Journal of Productivity Analysis, 18, 223–239, 2002

Cultivation Arrangements and the Cost Efficiency of Rice Farming in Taiwan*

MEI-YING HUANG mayin@mail.ntpu.edu.tw
Department of Economics, National Chung-Hsing University, Taipei, Taiwan

CLIFF J. HUANG cliff.huang@vanderbilt.edu
Department of Economics, Vanderbilt University, Nashville, Tennessee, U.S.A.

TSU-TAN FU tfu@econ.sinica.edu.tw
Institute of Economics, Academia Sinica, Taipei, Taiwan

Abstract

In this paper, a switching regression model is developed to analyze farmers' choice behavior and cost efficiency in field plowing arrangement in Taiwan. We find that the decision on the choice of plowing arrangement is determined by a cost comparison between self-plowing and hired-service, and other non-cost considerations, such as the availability of family labor and machinery, education level, non-farm income, age, and regional effects. Across a spectrum of farmer characteristics, empirical results indicate a potentially substantial cost-savings by hiring service for field plowing than by self-plowing. Self-plowing farmers also subject to a significant level of cost inefficiency.

JEL classification: C25, Q12

Keywords: stochastic frontier, cost efficiency, switching regression, cultivation arrangement, rice farming in Taiwan

1. Introduction

In this paper, we attempt to study farmers' cultivation arrangement on rice farming in Taiwan. Attention is focused on farmers' choice behavior and cost efficiency in field plowing arrangement. A switching regression model with a structural choice equation is developed to identify the dominant determinants of a farmer's decision. The choice of hired-service or self-work in field plowing is determined by both cost minimization of the plowing arrangements and other non-cost considerations. Thus, the realized plowing cost switches between the cost of hired-service and self-work. The novelty of the empirical modeling in this study is the application of a self-selection model to the measure of cost efficiency via a stochastic frontier framework.

Rice farming is one of the most important sources of employment and income for the rural population in Taiwan. In 1998, share of rice to total crop production was over 22%, and about 43% of farm households were rice farmers whose major agricultural income comes from rice farming. Unlike in other developing countries where large-scale tenancy farming and sharecropping contracts are the most widely observed practices, such farming arrangements are almost absent in agricultural faming in Taiwan. Due to the legal protection of tenancy rights on rent ceiling, lease contract, and land transaction, farmland owners in Taiwan are reluctant to lend their land to tenants for farming for fear of losing, or the costly reclamation of the land when it is needed.[1] Hence, the alternative farming arrangements such as entrusted farming, cooperative farming, and contract farming appear to be the most common contractual arrangements in Taiwan. Such practices are encouraged and actively promoted by Taiwan government to enhance farming efficiency and at the same time to discourage the concentration of farmland owned by absentee landlords. Farmland owners generally make informal cultivation contracts with other farmers or professional farm workers to perform certain tasks at different stages of farming in field plowing, seed sowing and transplanting, mid-term management (weeding, pesticide spraying, and fertilizer application), and harvesting. This type of cultivation arrangement allows farmland owners to pursue off-farm jobs without jeopardizing their land ownership. Furthermore, contract farming tends to be more productive because entrusted farmers or farm workers are generally professional and efficient managers who pool small family farming to engage in economies of scale operations.

Over the years, Taiwan's agricultural policy has emphasized the importance of and the need for enlarging the scale of farming operations to induce farm mechanization. The average size of farms in Taiwan is small; in 1998 they were on average 1.14 hectares with the size distribution skewed to the left. Forty-nine percent of farms have less than 0.75 hectares and only seventeen percent have more than 1.5 hectares. The small scale of segmented farms has made the adoption of machinery and new technology even more difficult, costly, and inefficient in Taiwan as compared with other countries with large-scale farming. The mechanization of small farming is economically profitable only by coordinating with other small farms in joint operations so as to maximize the utilization of machinery. According to a recent farm survey by the authors, only 37% of the sample farms own either a tiller or a tractor, even though almost 100% of field preparation and plowing in Taiwan are mechanized. A large percentage of small farms hire professional seasonal farm workers and machinery service during the peak seasons to work on field plowing (71%), transplanting (78%), and harvesting (92%). These cultivation jobs are often done in less time and are cheaper than self-cultivation.[2] The need for the contract farming and service is even more critical as more rural laborers migrate to urban areas for high-paying non-farm employment, thereby causing an acute seasonal labor shortage during the farming and harvesting months.

The plan of this paper is as follows. In Section 2, a switching regression model with a structural choice equation is developed to identify the dominant determinants of a farmer's decision to either hire service or self-work. The choice of hired-service or self-work in field plowing is determined by both cost minimization of the plowing arrangements and other non-cost considerations. Thus, the realized plowing cost switches between the cost of hired-service and self-work. Section 3 discusses the sample characteristics and empirical results. The sample data are obtained from the authors' 1998 survey on rice farms in Taiwan. The empirical estimation of the choice behavior and the cost efficiency in such field-plowing practice are presented. Results suggest that plowing cost differential and ownership of farm tillers are the dominant factors in determining the plowing arrangement. The farmer's education level, age, and farm income share are also shown to play an important role in the decision. Implications and conclusions are drawn in Section 4 that the forming of joint mechanized farming is essential to the farming efficiency in Taiwan.

2. Modeling the Choice and Measures of Inefficiency in Plowing Arrangements

A farmer's choice of cultivation arrangements on field plowing is described by a switching model and a criterion function.[3] Consider the ith farmer's need in plowing before sowing the rice seedling. The farmer could either self-plow the field or hire a plowing service. The costs of hired-plowing (C_H) and self-plowing (C_S) are determined by:

$$\text{Hired-plowing:} \quad C_{Hi} = X_{Hi}\beta_H + U_{Hi} \tag{1}$$

$$\text{Self-plowing:} \quad C_{Si} = X_{Si}\beta_S + U_{Si} \tag{2}$$

where X_{Hi} and X_{Si} are the vectors of cost determinants of the hired- and self-plowing options, respectively, and U_{Hi} and U_{Si} are the corresponding unobservable errors with mean zero and the variances, σ_H^2 and σ_S^2, respectively. Thus $X_{Hi}\beta_H$ and $X_{Si}\beta_S$ are the farmer's expectation of plowing cost at the time the choice is made. The farmer's decision on self- or hired-plowing depends on the criterion function,

$$\text{Criterion function:} \quad I_i^* = Z_i\gamma + \delta(C_{Si} - C_{Hi}) - U_i \tag{3}$$

where Z_i is a vector of variables not exclusively X_{Hi} or X_{Si}, and γ and δ are coefficients. The random error U_i reflects unobservable factors influencing the selection of plowing arrangements. The vector (U_{Hi}, U_{Si}, U_i) of the random errors is assumed to be jointly normal with zero mean and unrestricted variance-covariance matrix.

The criterion function (3) implies that the ith farmer's decision about the field-plowing arrangement depends on the cost differential between self-plowing and hired-plowing service as well as the non-cost considerations represented by the variables Z_i. The Z_i variables include the farmer's characteristics of age, education level, non-farm employment opportunity, and others. Since the ith farmer may choose either hired-plowing or self-plowing, only one of the cost variables C_{Hi} or C_{Si} is observed, depending on whether $I_i^* > 0$ or $I_i^* \leq 0$. If the hired-plowing service is chosen, the observed cost $C_i = C_{Hi}$. Otherwise, $C_i = C_{Si}$ if self-plowing is selected. The observed cost thus depends on the probability of self-selection, $\Pr(I_i^* > 0)$ or $\Pr(I_i^* \leq 0)$.

The estimation of the model, cost equations (1), (2), and the criterion function (3) is a standard two-stage procedure of Lee (1978) and Willis and Rosen (1979). By substituting the plowing cost equations C_{Hi} and C_{Si} into I_i^*, the reduced form criterion function can be written as,

$$I_i^* = Z_i\gamma + \delta(X_{Si}\beta_S - X_{Hi}\beta_H) + \delta(U_{Si} - U_{Hi}) - U_i \equiv Z_i^*\gamma^* - U_i^* \tag{4}$$

where $Z_i^* = (Z_i, X_{Si}, X_{Hi})$, and the corresponding reduced form error U_i^* is normalized to have unit variance. The normalized coefficient γ^* is defined accordingly. The reduced form criterion function is a typical probit choice model with the selection index

$$I_i = 1 \quad \text{and} \quad C_i = C_{Hi} \text{ is observed,} \quad \text{if } I_i^* > 0$$
$$I_i = 0 \quad \text{and} \quad C_i = C_{Si} \text{ is observed,} \quad \text{if } I_i^* \leq 0$$

The cost equations (1) and (2) are a standard self-selection model. Define two inverse Mill ratios,

$$W_{Hi} = \frac{\phi(Z_i^* \gamma^*)}{\Phi(Z_i^* \gamma^*)} \quad \text{and} \quad W_{Si} = \frac{\phi(Z_i^* \gamma^*)}{1 - \Phi(Z_i^* \gamma^*)} \tag{5}$$

where $\phi(.)$ and $\Phi(.)$ are the standard normal density and distribution functions, respectively. Given the observations on hired-plowing farmers, $C_i = C_{Hi}$, the hired-plowing equation (1) can be written as:

$$C_{Hi} = X_{Hi}\,\beta_H - \sigma_{H^*} W_{Hi} + \varepsilon_{Hi}, \qquad \text{for } I_i = 1 \tag{6}$$

where $\sigma_{H^*} = \text{Cov}(U_{Hi}, U_i^*)$ and $\varepsilon_{Hi} = U_{Hi} + \sigma_{H^*} W_{Hi}$ with $E(\varepsilon_{Hi} \mid I_i^* > 0) = 0$. Similarly given the observations on self-plowing, $C_i = C_{Si}$, the self-plowing equation becomes

$$C_{Si} = X_{Si}\,\beta_S + \sigma_{S*} W_{Si} + \varepsilon_{Si}, \qquad \text{for } I_i = 0 \tag{7}$$

where $\sigma_{S^*} = \text{Cov}(U_{Si}, U_i^*)$ and $\varepsilon_{Si} = U_{Si} - \sigma_{S^*} W_{Si}$. Since $E(\varepsilon_{Si} \mid I_i^* \leq 0) = 0$, the conditional mean of C_{Si}, $E(C_{Si} \mid I_i = 0) = X_{Si}\beta_S + \sigma_{S^*} W_{Si}$, is the self-selected, expected self-plowing cost.

In the first-stage of estimating the model, the probit estimate $\hat{\gamma}^*$ of the reduced form coefficient γ^* is obtained from (4) and the two estimates $\hat{W}_{Hi}$ and $\hat{W}_{Si}$ of the inverse Mill ratios are computed from (5). Replacing W_{Hi} and W_{Si} with $\hat{W}_{Hi}$ and $\hat{W}_{Si}$, the estimates $(\hat{\beta}_H, \hat{\beta}_S, \hat{\sigma}_{H^*}, \hat{\sigma}_{S^*})$ of the coefficients in (6) and (7) can be obtained by a least-squares method. With these estimates, the coefficients (γ, δ) of the structural decision criterion function (3) can then be consistently estimated in the second stage by replacing (C_{Hi}, C_{Si}) with the estimates $(X_{Hi}\hat{\beta}_H, X_{Si}\hat{\beta}_S)$. Once the model of the choice is estimated, the cost differential in the plowing arrangements can be compared based on the predicted costs, $\hat{C}_{Hi} = X_{Hi}\hat{\beta}_H$ and $\hat{C}_{Si} = X_{Si}\hat{\beta}_S$.

The above switching model and the two-stage estimation technique focus on the determinants of choice and the cost comparison with the implicit or explicit assumption that the field plowing is efficient, i.e., operating at the minimum cost frontier. However, there are few compelling reasons for assuming efficient utilization or efficient allocation of inputs in operation, particularly if self-plowing is chosen. Typically, hired-plowing services charge according to field size and geographic location. Farmers do not bear the cost due to plowing mismanagement or input allocative inefficiency. The expected cost of hired-plowing $X_{Hi}\beta_H$ in the cost regression (1) is also the minimum cost expected to incur if hired service is performed. On the other hand, to a self-plowing farmer, the cost regression (2) inevitably inherits an element of cost inefficiency in operation. In the spirit of the stochastic frontier literature on efficiency, the residual of U_{Si} in the cost regression (2) can be further decomposed to measure the self-plowing cost inefficiency.

Denote C_{Si}^{min} to be the minimum cost frontier of self-plowing. The deviation of the self-plowing cost C_{Si} from the frontier, $C_{Si} - C_{Si}^{min}$, is a composite error which consists of a symmetric, two-sided random error v_i, and a one-sided component u_i. That is, $C_{Si} - C_{Si}^{min} = v_i + u_i$. The symmetric error with $E(v_i) = 0$ represents the statistical noise and the one-sided error with $E(u_i) > 0$ captures the effects of inefficiency. The stochastic frontier formulation, $C_{Si} = C_{Si}^{min} + v_i + u_i$, is essentially an alternative expression of the self-plowing cost equation in (2),

$$\begin{aligned} C_{Si} &= \left\{C_{Si}^{min} + E(u_i)\right\} + \{v_i + u_i - E(u_i)\} \\ &= X_{Si}\beta_S + U_{Si} \end{aligned} \tag{8}$$

where $X_{Si}\beta_S = \{C_{Si}^{min} + E(u_i)\}$ and $U_{Si} = \{v_i + u_i - E(u_i)\}$.

Since $E(u_i) > 0$, the cost determinant of self-plowing shifts up the minimum cost frontier C_{Si}^{min} by the constant $E(u_i)$ via the regression intercept in $X_{Si}\beta_S$. However, the coefficient β_S is estimated neither by the maximum likelihood method of Aigner, Lovell, and Schmidt (1977) nor by the corrected ordinary least-squares method of Olson, Schmidt, and Waldman (1980). It is estimated via a two-stage procedure given in (7) with a correction of self-selection bias.[4]

Given the observations on self-plowing $C_i = C_{Si}$ and the estimate of β_S from the second-stage in (7), the residual

$$U_{Si} = C_i - X_{Si}\beta_S = v_i + u_i - E(u_i), \qquad \text{for } I_i = 0 \tag{9}$$

can be used to decompose the individual farmer cost inefficiency u_i.

Assume that v_i is normally distributed with means 0 and variance σ_v^2, and the u_i is truncated from below at zero from a normal distribution with mean zero and variance σ_u^2.[5] Given the estimate of the self-plowing predicted cost, $X_{Si}\hat{\beta}_S$, the variances σ_v^2 and σ_u^2 can be estimated from the deviation in (9) by the method of moments of Olson et al. (1980). These estimates are

$$\hat{\sigma}_u^2 = \left(\frac{m_3}{\sqrt{2/\pi}(4/\pi - 1)}\right)^{2/3}; \quad \hat{\sigma}_v^2 = m_2 - \left(1 - \frac{2}{\pi}\right)\hat{\sigma}_u^2$$

where m_2 and m_3 are, respectively, the second and third central moments of the residuals, $\hat{U}_{Si} = C_i - X_{Si}\hat{\beta}_S$. Since $E(u_i) = \sqrt{2/\pi}\sigma_u$ under the truncated normal distribution, the composite error $\varepsilon_i = v_i + u_i$ can be obtained by adding back $E(u_i)$ to (9),

$$\varepsilon_i = U_{Si} + \sqrt{2/\pi}\sigma_u,$$

for $I_i = 0$. Following the approach of Jondrow, et al. (1982), the individual self-plowing farm-specific inefficiency can then be estimated by the conditional mean of u_i given the composite error $\varepsilon_i = v_i + u_i$,

$$E(u_i \mid \varepsilon_i) = \mu_{i^*} + \sigma_* \frac{\phi(\mu_{i^*}/\sigma_*)}{\Phi(\mu_{i^*}/\sigma_*)}$$

where $\mu_{i^*} = \varepsilon_i\sigma_u^2/\sigma^2$, $\sigma_*^2 = \sigma_u^2\sigma_v^2/\sigma^2$, and $\sigma^2 = \sigma_u^2 + \sigma_v^2$. The individual self-plowing minimum cost frontier can also be estimated accordingly:

$$E\left(C_{Si}^{min} \mid \varepsilon_i\right) = X_{Si}\beta_S - E(u_i \mid \varepsilon_i)$$

Alternatively, if a logarithmic cost function is estimated, i.e., $\ln C_{Si} = X_{Si}\beta_S + U_{Si}$, and the composite error is specified accordingly, $\ln C_{Si} - \ln C_{Si}^{min} = v_i + u_i$, then the exponential, $\exp(u_i)$, captures the cost inefficiency. Battese and Coelli (1988) propose an alternative estimate of an individual efficiency,

$$E(e^{-u_i} \mid \varepsilon_i) = \frac{\Phi(\mu_{i*}/\sigma_* - \sigma_*)}{\Phi(\mu_{i*}/\sigma_*)} \exp\left(-\mu_{i*} + \frac{1}{2}\sigma_*^2\right) \tag{10}$$

The individual self-plowing minimum cost frontier can also be estimated accordingly:

$$E\left(C_{Si}^{min} \mid \varepsilon_i\right) = \exp\left(X_{Si}\beta_S + \frac{1}{2}\sigma_S^2\right) E(e^{-u_i} \mid \varepsilon_i) \tag{11}$$

where σ_S^2 is the variance of the error U_{Si}. In the following empirical model, we specify a logarithmic cost function and use equations (10) and (11) to compute self-plowing cost efficiency and the minimum cost frontier.

Bera and Sharma (1999) have derived the conditional variance and the $100(1-\alpha)\%$ confidence interval for the individual efficiency. Define

$$\text{Lower} = \mu_{i*} + \Phi^{-1}\left[\frac{\alpha}{2} + \left(1 - \frac{\alpha}{2}\right)\Phi\left(-\frac{\mu_{i*}}{\sigma_*}\right)\right]\sigma_*$$

$$\text{Upper} = \mu_{i*} + \Phi^{-1}\left[1 - \frac{\alpha}{2}\left\{1 - \Phi\left(-\frac{\mu_{i*}}{\sigma_*}\right)\right\}\right]\sigma_*$$

The lower confidence bound (LCB) and the upper confidence bound (UCB) are then

$$\text{LCB} = \exp(-\text{Upper}) \tag{12}$$

$$\text{UCB} = \exp(-\text{Lower}) \tag{13}$$

3. Sample Characteristics and Empirical Estimation

The data in this study were taken from the authors' survey of a stratified random sample of 400 Taiwan rice farmers in a three-month period, January to March of 1998.[6] In the survey, the individual farmer was asked to report his decision about the cultivation arrangements in rice farming. The cost of field plowing by selection and the farmer's and the farm's characteristics were noted. Of the 400 interviews, 348 farm observations are complete and usable in this study.

Table 1 summarizes the sample statistics of both hired-plowing and self-plowing farmers. The average self-plowing farms are twice as large as the hired-plowing farms in cultivated acreage. In respect to percentage, the self-plowing farms rely more heavily on the farm as the source of household income than the hired-plowing farms. This correlation implies that the self-plowing farmers are more likely to be full-time farmers than the hired-plowing farmers. The table also shows that only 13% of hired-plowing farmers owned tillers or tractors, whereas most of self-plowing farmers own at least one piece of farm equipment.[7] The available family labor is approximated by the size of the household currently residing at the farm. There is more available family labor in the self-plowing farms. It is slightly less costly per hectare for the self-plowing than in the hired-plowing practice, yet the cost variation is significantly larger than in self-plowing. Such large variation would imply a wide range of farming inefficiency for self-plowing farms in the sample. Since the current practice in hired-plowing charges the service by the field size in hectares, the cost shares of

Table 1. Sample statistics: mean and standard deviation.

Variable	Definition	Full-Sample (348)	Hired-Service (248)	Self-Plowed (100)
Farm characteristics				
HECTARE	Cultivated area (0.1 ha)	13.48 (14.54)	10.42 (9.07)	21.07 (21.32)
FY	Farm income/farm household income (%)	46.98 (20.44)	44.71 (20.10)	52.63 (20.28)
TILLER	Owned tiller or tractor = 1, otherwise = 0	0.37 (0.48)	0.13 (0.34)	0.93 (0.25)
HSIZE	Household size (persons)	3.67 (2.10)	3.51 (2.08)	3.98 (2.10)
Ave. Cost	Average plowing cost, labor & machinery costs (NT$/0.1 ha)	NA	1067.66 (118.24)	1056.15 (599.51)
Labor-share	Labor cost share (%)	NA	NA	41.36 (24.40)
Mach-share	Machinery cost share (%)	NA	NA	58.10 (24.18)
Farmer characteristics				
AGE	Farmer's age (year)	58.26 (11.39)	59.29 (11.17)	55.71 (11.60)
AGE65	Farmer's age over 65 = 1, otherwise = 0	0.26 (0.44)	0.29 (0.46)	0.18 (0.38)
EDU	Farmer's years of education	7.00 (3.34)	6.92 (3.48)	7.17 (2.98)
NFJOB	Has non-farm job = 1, otherwise = 0	0.17 (0.37)	0.17 (0.38)	0.15 (0.36)
NORTH	Located in northern region = 1, otherwise = 0	0.13 (0.34)	0.06 (0.24)	0.31 (0.46)
EAST	Located in eastern region = 1, otherwise = 0	0.05 (0.23)	0.04 (0.20)	0.08 (0.28)

labor and machinery are not observed. However, the cost shares for the self-plowing farms are 42% and 58%, respectively.

The average age of the farmers in the survey is 58 years old, which indicates a potential aging problem in Taiwan rice farming. Nevertheless, the self-plowing farmers are relatively younger than the hired-plowing farmers and the older farmers over 65 years of age tend to contract out the field plowing. Self-plowing farmers have slightly more years of education than the hired-plowing farmers. Even though part-time farming is quite popular in many Asian countries, the survey shows only 20% of the sample farmers as having other non-farm employment.

The variables used in estimating the two cost equations (1) and (2) of field-plowing practice include the hectare plowed (HECTARE), wage rate of labor (PL), machine cost per hectare (PM), and two regional dummy variables, north region (NORTH) and east region (EAST) to capture the regional effects. Since there is no record on family labor costs, the market wage for hired labor is approximated. Machine cost per hectare is computed by dividing the sum of machinery depreciation and fuel expenses by hectares plowed. Since the cost of hired-plowing varies only according to the plowing size, only the hectare plowed and the two regional dummies are included as the independent variables. Furthermore, the condition of linear homogeneity of degree one in wage rate (PL) and price of machine (PM) is imposed on the self-plowing cost function. In the logarithmic form, the two cost equations are specified as:

$$\begin{aligned}\ln(C_{Hi}) &= \beta_{H0} + \beta_{H1}\ln(\text{HECTARE})_i + \beta_{H2}(\text{EAST})_i + \beta_{H3}(\text{NORTH})_i + U_{Hi}\\ \ln(C_{Si}) &= \beta_{S0} + \beta_{S1}\ln(\text{HECTARE})_i + \beta_{S2}(\text{EAST})_i + \beta_{S3}(\text{NORTH})_i\\ &\quad + \beta_{S4}\ln(\text{PL})_i + (1-\beta_{S4})\ln(\text{PM})_i + U_{Si}\end{aligned}$$

Besides the cost differential, $(C_{Si} - C_{Hi})$, the variables included in the decision function (3) are the Z variables. These are household size (HSIZE), education level in year (EDU), farm income as percentage of household income (FY), and two other dummy variables: AGE65 = 1 if farmer's age is over 65, and AGE65 = 0, otherwise; TILLER = 1 if farmer owns tiller or tractor, and TILLER = 0, otherwise. The decision equation is specified as:

$$\begin{aligned}I_i^* &= \gamma_0 + \gamma_1\ln(\text{HSIZE})_i + \gamma_2(\text{EDU})_i + \gamma_3(\text{FY})_i + \gamma_4(\text{AGE65})_i + \gamma_5(\text{TILLER})_i\\ &\quad + \gamma_6(\text{EAST})_i + \gamma_7(\text{NORTH})_i + \delta\{\ln(C_{Si}) - \ln(C_{Hi})\} - U_i\end{aligned}$$

The observed cost $C_i = C_{Hi}$ and $I_i = 1$ if $I_i^* > 0$ and $C_i = C_{Si}$ and $I_i = 0$ if $I_i^* \leq 0$.

Household size (HSIZE) reflects the condition of family labor supply on the farm. A farm with relatively abundant family labor would tend to self-plow rather than hire service and a negative sign of γ_1 is expected. The opportunity cost for self-plowing is higher for an educated farmer since it is easier for him to secure high-paying non-farm employment. It is expected that the influence of education years (EDU) on the decision for hired-plowing is positive. It is reasonable to assume that farmers who rely on farming as the source of household income would have a high probability of self-plowing and are likely to be full-time farmers. A negative effect of farm income percentage (FY) is expected. An aging farmer (AGE65) tends to hire service for hard labor and the positive sign on γ_4 for hired-plowing is expected. Farmers who invest in equipment and machinery would have a tendency to choose self-plowing. The coefficient γ_5 for the variable (TILLER) is negative.[8] Regional factors reflect the regional-specific resources conditions in the supply of farm labor and capital. The farmers in northern Taiwan often experience a chronic shortage of farm labor and opt to induce farm mechanization. The northern region (NORTH) farmers therefore have a high probability to select self-plowing.

Table 2 tabulates the estimated cost equations of the plowing arrangement with the selectivity bias W_H and W_S adjusted. These estimates are based on the two-stage procedure described in equation (6) and (7). The selectivity bias terms, W_H and W_S, of equation (5) are computed from the estimates of the reduced form criterion function given in Table 3. The farm size (HECTARE) and input prices (PL, PM) all have the expected signs and are statistically significant. The hired-plowing cost in the northern region (NORTH) is relatively higher than in the other region, which confirms the hypothesis of chronic farm labor shortage in the region. The elasticity of plowing cost with respect to farm size is much larger in hired-plowing than in self-plowing. This correlation is expected since the hired-

Table 2. Estimated cost equations of the plowing arrangement with dependent variables: $\ln(C_{Hi})$ and $\ln(C_{Si})$.

Variable	Hired-Plowing: $\ln(C_{Hi})$	Self-Plowing: $\ln(C_{Si})$
Constant	6.9950**	1.4074**
	(283.7021)	(9.2635)
ln(HECTARE)	0.9914**	0.8721**
	(86.5558)	(18.5332)
ln(PL)		0.4095**
		(8.1198)
ln(PM)		0.5905**
		(11.7085)
EAST	−0.0946**	−0.2396*
	(−2.1375)	(−1.8729)
NORTH	0.0401	−0.0433
	(1.0801)	(−0.6079)
W_H	−0.0292	
	(−1.1433)	
W_S		−0.0639
		(−0.6949)
Observations	248	100
Adjusted R^2	0.9702	0.8874

Note: Figures in parentheses are t-ratios. ** indicates significance at 0.05 level and * at 0.10 level.

plowing service charges by farm size and not by labor or machinery cost separately. For self-plowing farmers, the labor cost share, the coefficient of ln(PL), is about 18 percentage points less than the machinery cost share. The smaller labor share reflects the increasing mechanization of farming in Taiwan. The coefficients of the selectivity bias adjustment, W_H and W_S, have the expected sign with $\sigma_{H*} = 0.029$ (negative of the W_H coefficient) and $\sigma_{S*} = -0.064$. This result implies that those who chose hired-plowing are better than average hired-plowing farmers in terms of cost savings. Those who chose self-plowing are better than average self-plowing farmers.

The estimates of the structural form and the reduced form criterion functions are given in Table 3. The most significant factors determining the plowing arrangement decision are the plowing cost differential, $\ln(C_{Si}) - \ln(C_{Hi})$ and the ownership of a tiller. For every one percent increase in the cost of self-plowing over hired-plowing, the probability of hiring service increases on average by 0.20.[9] A farmer who owns a tiller has a 0.31 higher probability of choosing self-plowing. This result is consistent with the farm survey responds that the main reason for hired-plowing is the lack of tiller or tractor. Other determinants, education, the share of farm income, age, and machinery ownership, also play a significant role in the decision.[10] Consistent with the results of the cost function estimates, the northern farmers select self-plowing more often than those in other regions. Although the labor cost significantly determines the cost of plowing, it does not seem to influence the plowing arrangement decision. On the other hand, the cost of machinery has a significant adverse decision on self-plowing. The estimated results from the criterion equations seem

Table 3. Probit estimates of the criterion equations with dependent variable: $I_i = 1$ for hired-plowing, $I_i = 0$ for self-plowed.

Variable	Structural Form Equation	Reduced Form Equation
Constant	1.7613**	−7.7901**
	(2.9168)	(−2.4753)
ln(HSIZE)	−0.1164	−0.1156
	(−0.5205)	(−0.5129)
EDU	0.2641**	0.2469*
	(2.0188)	(1.8585)
FY	−1.2881**	−1.3507**
	(−2.1929)	(−2.2499)
AGE65	0.7366**	0.7003**
	(2.2709)	(2.1465)
TILLER	−2.4787**	−2.4794**
	(−9.3668)	(−9.1889)
EAST	0.8104*	0.4925
	(1.8316)	(1.0891)
NORTH	−0.6015**	−0.6815**
	(−2.0499)	(−2.1805)
$\ln(C_{Si}) - \ln(C_{Hi})$	1.7235**	
	(4.4388)	
ln(HECTARE)		−0.1179
		(−0.7382)
ln(PL)		0.5211
		(1.2187)
ln(PM)		1.1339**
		(4.0388)
Observations	348	348
McFadden R^2	0.6094	0.6110
LR Statistic	254.4050	255.0626

to suggest that the major determinants of the Taiwan farmer's decision about field-plowing arrangements include both cost and non-cost considerations.

Table 4 shows the sample estimates of cost-savings in hired-plowing over self-plowing and the measure of efficiency in self-plowing for all sample farmers, and for subgroups by farm size, by age, and by full-time versus part-time farming status. Since the logarithmic cost functions are estimated, equation (10) and (11) are used to compute the inefficiency and the cost frontier for self-plowing farmers. The columns are essentially the decomposition of

$$\frac{E(C_{Hi})}{E(C_{Si})} = \frac{E\left(C_{Si}^{min} \mid \varepsilon_i\right)}{E(C_{Si})} \frac{E(C_{Hi})}{E\left(C_{Si}^{min} \mid \varepsilon_i\right)}$$

The decomposition uses the estimate of the individual farm's cost frontier, $E(C_{Si}^{min} \mid \varepsilon_i)$, instead of the average deterministic cost frontier C_{Si}^{min}. The decomposed two components measure the individual farm-specific efficiency and cost-savings. The column on cost-

Table 4. Cost-savings in hired-plowing and efficiency in self-plowing.

Subgroup Farms	Savings in Hired-Plowing	Efficiency in Self-Plowing	Savings in Efficient Self-Plowing
All farms	10.00% (348)	0.8132 (100) [0.7632 − 0.8525]	58.22% (100)
Large farms HECTARE > 0.96	5.21% (177)	0.8134 (70) [0.7615 − 0.8507]	80.16% (70)
Small farms HECTARE ≤ 0.96	25.67% (171)	0.8129 (30) [0.7671 − 0.8568]	7.00% (30)
Older farmers AGE > 65	15.62% (90)	0.7893 (17) [0.7475 − 0.8269]	98.16% (17)
Young farmers AGE ≤ 65	8.00% (258)	0.8182 (83) [0.7666 − 0.8579]	50.04% (83)
Full-time farmers FY > 0.5	5.30% (146)	0.8278 (53) [0.7847 − 0.8640]	54.58% (53)
Part-time farmers FY ≤ 0.5	14.05% (202)	0.8082 (47) [0.7558 − 0.8451]	62.32% (47)

Note: The "Savings in Hired-Plowing" column includes both 248 hired- and 100 self-plowing farms, while the other two columns, "Efficiency in Self-Plowing" and "Savings in Efficient Self-Plowing," includes only the 100 self-plowing farms. The number of farms in each subgroup is in parentheses, and the number in brackets is the sample average of the 95% confidence interval for the individual self-plowing efficiency.

savings in hired-plowing given in Table 4 is the sample average percentage increment of the self-plowing cost over the hired-plowing cost. For each subgroup, it is the average of

$$\text{Savings in Hired-Plowing} = 100^* \left(1 - \frac{E(C_{Hi})}{E(C_{Si})}\right) = 100^* \left(1 - \frac{\exp\left(X_{Hi}\beta_H + \frac{1}{2}\sigma_H^2\right)}{\exp\left(X_{Si}\beta_S + \frac{1}{2}\sigma_S^2\right)}\right)$$

The subgroups in this column include both self- and hired-plowing farmers, 348 farms in total. The exponentials, $\exp(X_{Hi}\beta_H + \frac{1}{2}\sigma_H^2)$ and $\exp(X_{Si}\beta_S + \frac{1}{2}\sigma_S^2)$, are used here since the logarithmic cost functional form is estimated. The second column on the efficiency in self-plowing is the sample average of the ratio of the minimum self-plowing cost frontier over the self-plowing cost,

$$\text{Efficiency in Self-Plowing} = \frac{E\left(C_{Si}^{min} \mid \varepsilon_i\right)}{E(C_{Si})} = E(e^{-u_i} \mid \varepsilon_i)$$

The number in the bracket are the sample average of the 95% confidence intervals for the individual self-plowing efficiency calculated from equation (12) and (13). Since our interest is in the efficiency of those who choose self-plowing, the subgroups in this column include only the 100 self-plowing farms. The last column on the cost-savings in efficient self-plowing is the average percentage increment of the hired-plowing cost over the minimum self-plowing cost frontier. It tries to answer the question of whether hired-plowing is cost saving if the self-plowing farmer were perfectly efficient. If $E(C_{Hi}) < E(C_{Si}^{min} \mid \varepsilon_i)$, there is no incentive for farmers to self-plow fields even under the best circumstances. This is the average over the 100 self-plowing farms.

$$\text{Savings in Efficient Self-Plowing} = 100^* \left(\frac{E(C_{Hi})}{E\left(C_{Si}^{min} \mid \varepsilon_i\right)} - 1 \right)$$

On average, the cost of self-plowing is about 10% higher than the cost of hired-plowing. The cost-savings in hired-plowing is even more significant for small farms. The cost-savings is more than 25% for small farms with less than 0.96 hectares, the median farm size. The outcome is consistent with the long-standing view that, short of consolidating small and fragmented parcels of farmland, the economies of scale are feasible only by organizing small farms into farming groups to hire jointly service in field plowing, in seed sowing, transplanting seedlings, and in harvesting. Aging farmers over 65 years old benefit significantly, in the range of 15% cost-savings, by hiring service. For convenience, if a farm income is less than half of the household income, $FY < 0.5$, it is considered as part-time farming. The potential cost saving by hiring service for part-time farmers is estimated to be about 14%, which is more than twice that of full-time farmers at 5.3%.

As shown in the second column of Table 4, there is significant cost inefficiency in self-plowing. For the sample as a whole, the cost efficiency for self-plowing is 0.8132. Although there is no significant variation in (in)efficiency by farm size, aging farmers are less efficient in field plowing. It costs older farmers 21% (i.e., cost inefficiency) over the minimum cost frontier as compared to 18% for younger farmers. This finding reconfirms the dilemma facing rice farmers in Taiwan. With rapid industrialization and the migration of farm labors to non-farm sectors, the number of full-time and young farmers has dropped dramatically. For those part-time self-plowing farmers, the inefficiency is about 2% higher than those full-time self-plowing farmers. Part-time farming has contributed to the deterioration of productivity and efficiency. The lower and upper bounds of the 95% confidence intervals for the 100 self-plowing farms are tabulated in Table 5. The estimated standard errors of the cost efficiency are also listed (see Bera and Sharma (1999) for the calculation of STD). The confidence intervals depicted in Figure 1 are consistent with Bera and Sharma prediction that the most efficient self-plowing farm gives the smallest interval. However, the width of the confidence interval does not decrease monotonically with the efficiency.

The last column of Table 4 shows that, for all subgroups, the cost savings in hiring service in plowing disappears when the self-plowing farmers were 100% efficient in reaching the minimum cost frontier. In fact, there is a significant cost-savings in self-plowing at the fully efficient level. The hired-plowing cost on average is 58% higher than the minimum cost of self-plowing. For large farms, the hired-plowing cost is 80% more than the minimum self-plowing cost. Fully efficient larger farms and older farmers have the most to gain in self-plowing. The gain by part-time farmers is also significant if they are efficient in self-plowing.

Table 5. Self-plowing farms' cost efficiency, the 95% confidence bounds, and the standard errors.

Farm	Efficiency	LCB	UCB	STD
1	0.4552	0.4268	0.4850	0.0149
2	0.4818	0.4517	0.5133	0.0157
3	0.4921	0.4614	0.5243	0.0161
4	0.4937	0.4629	0.5260	0.0161
5	0.5181	0.4858	0.5521	0.0169
6	0.5236	0.4909	0.5579	0.0171
7	0.5472	0.5131	0.5831	0.0179
8	0.5482	0.5139	0.5840	0.0179
9	0.5586	0.5237	0.5952	0.0182
10	0.5669	0.5315	0.6040	0.0185
11	0.5824	0.5460	0.6205	0.0190
12	0.5851	0.5486	0.6234	0.0191
13	0.5854	0.5489	0.6238	0.0191
14	0.5860	0.5494	0.6244	0.0191
15	0.5938	0.5567	0.6327	0.0194
16	0.5940	0.5569	0.6329	0.0194
17	0.5943	0.5571	0.6332	0.0194
18	0.6582	0.6171	0.7013	0.0215
19	0.6636	0.6221	0.7070	0.0217
20	0.6753	0.6332	0.7195	0.0220
21	0.6842	0.6415	0.7290	0.0223
22	0.6910	0.6479	0.7362	0.0226
23	0.6968	0.6533	0.7424	0.0227
24	0.6972	0.6536	0.7428	0.0228
25	0.6975	0.6539	0.7431	0.0228
26	0.7022	0.6584	0.7482	0.0229
27	0.7061	0.6620	0.7523	0.0230
28	0.7185	0.6736	0.7655	0.0234
29	0.7332	0.6874	0.7812	0.0239
30	0.7407	0.6944	0.7892	0.0242
31	0.7530	0.7060	0.8023	0.0246
32	0.7582	0.7108	0.8078	0.0247
33	0.7789	0.7303	0.8299	0.0254
34	0.7888	0.7395	0.8404	0.0257
35	0.7899	0.7405	0.8416	0.0258
36	0.7919	0.7425	0.8438	0.0258
37	0.7973	0.7475	0.8495	0.0260
38	0.7999	0.7499	0.8522	0.0261
39	0.8054	0.7551	0.8582	0.0263
40	0.8100	0.7594	0.8630	0.0264
41	0.8114	0.7608	0.8645	0.0265
42	0.8116	0.7610	0.8648	0.0265
43	0.8127	0.7619	0.8659	0.0265
44	0.8138	0.7629	0.8670	0.0266
45	0.8162	0.7652	0.8697	0.0266
46	0.8189	0.7678	0.8725	0.0267
47	0.8237	0.7723	0.8777	0.0269
48	0.8301	0.7782	0.8844	0.0271
49	0.8356	0.7834	0.8903	0.0273

(*continued*)

Table 5. (*Continued*)

Farm	Efficiency	LCB	UCB	STD
50	0.8377	0.7854	0.8925	0.0273
51	0.8404	0.7880	0.8955	0.0274
52	0.8441	0.7914	0.8994	0.0275
53	0.8491	0.7960	0.9047	0.0277
54	0.8526	0.7994	0.9084	0.0278
55	0.8653	0.8113	0.9220	0.0282
56	0.8659	0.8118	0.9226	0.0283
57	0.8680	0.8138	0.9248	0.0283
58	0.8760	0.8213	0.9334	0.0286
59	0.8775	0.8227	0.9350	0.0286
60	0.8834	0.8282	0.9412	0.0288
61	0.8842	0.8290	0.9421	0.0288
62	0.8850	0.8297	0.9429	0.0289
63	0.8865	0.8312	0.9445	0.0289
64	0.8909	0.8353	0.9491	0.0290
65	0.8926	0.8369	0.9510	0.0291
66	0.8980	0.8419	0.9566	0.0292
67	0.9062	0.8497	0.9650	0.0294
68	0.9071	0.8505	0.9659	0.0294
69	0.9081	0.8515	0.9670	0.0294
70	0.9192	0.8621	0.9774	0.0294
71	0.9268	0.8696	0.9836	0.0292
72	0.9465	0.8903	0.9942	0.0274
73	0.9480	0.8920	0.9947	0.0271
74	0.9486	0.8927	0.9949	0.0270
75	0.9496	0.8939	0.9952	0.0268
76	0.9528	0.8977	0.9960	0.0262
77	0.9566	0.9024	0.9968	0.0253
78	0.9585	0.9049	0.9972	0.0248
79	0.9621	0.9098	0.9977	0.0238
80	0.9748	0.9300	0.9990	0.0188
81	0.9776	0.9355	0.9992	0.0174
82	0.9786	0.9374	0.9992	0.0169
83	0.9787	0.9378	0.9992	0.0168
84	0.9792	0.9388	0.9993	0.0165
85	0.9799	0.9403	0.9993	0.0161
86	0.9825	0.9461	0.9994	0.0145
87	0.9831	0.9473	0.9995	0.0142
88	0.9840	0.9495	0.9995	0.0136
89	0.9865	0.9559	0.9996	0.0119
90	0.9875	0.9586	0.9996	0.0112
91	0.9882	0.9606	0.9997	0.0106
92	0.9896	0.9647	0.9997	0.0095
93	0.9900	0.9658	0.9997	0.0092
94	0.9910	0.9688	0.9998	0.0084
95	0.9923	0.9730	0.9998	0.0073
96	0.9941	0.9790	0.9998	0.0057
97	0.9956	0.9843	0.9999	0.0042
98	0.9961	0.9883	0.9999	0.0029
99	0.9961	0.9897	1.0000	0.0024
100	0.9963	0.9930	1.0000	0.0012

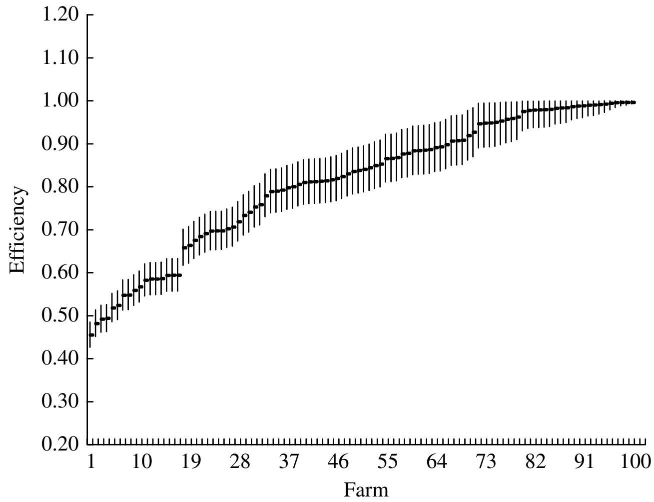

Figure 1. The 95% confidence intervals for the self-plowing farms.

4. Concluding Remarks

In this paper, we develop a switching regression model to analyze rice farming practices in field plowing and its cost efficiency in Taiwan. We find that the decision on the choice of plowing arrangement is determined by a cost comparison between self-plowing and hired-service, and other non-cost considerations. The non-cost factors include the availability of family labor and machinery, education level, non-farm income, age, and regional effects. Across a spectrum of farmer characteristics, empirical results indicate a potentially substantial cost-savings by hiring service for field plowing than by self-plowing. Self-plowing farmers are also subject to a significant level of cost inefficiency.

Such cost-savings findings seem to imply that over 70 percent of the sample farmers who hired service for field-plowing practice made the right choice of plowing arrangement. While current contractual farming patterns in Taiwan are shown to be beneficial to those, mostly small, farmers contracting out plowing service, they also provide a service opportunity to those self-plowing farmers in expanding their farming scale through field plowing practice.

Since rice matures twice a year and the peak seasons for field preparation vary by region, the demand for field–plowing service can last for several months, starting in the south and moving north. A tiller-owner should be able to utilize fully his machinery service and a professional farming team should have ample demand for plowing service. However, the key for tiller owners and professional farming teams to enjoy the economy of scale for the service depends on the search and matching of the demand. Our survey indicates that those hired-plowing service farms mostly obtained the service from the neighboring farmers and, only a few obtained the service from professional farming teams due to limited information on their availability. A public service intermediation or institution, which provides market information on plowing service, could be beneficial to both contracting parties. With such mediation, a farmer could obtain a cost efficient and quality service, whereas a professional farming team could enjoy the economies of scale operation.

The empirical conclusion presented in this study is consistent with the notion that the scarcity of farmland and the rigid tenancy system constrain the expansion in farm size and limit farm mechanization for efficient and productive farming in Taiwan. An agricultural policy that encourages the forming of joint mechanized farming is essential to the survival of rice farmers in Taiwan.

Acknowledgments

The authors gratefully acknowledge helpful comments and suggestions from C. A. Knox Lovell and Subal C. Kumbhakar, and two referees. The early version of the paper was presented at the 1999 Taipei International Conference on Efficiency and Productivity Growth, Taipei, Taiwan, July 30–31, 1999.

Notes

1. A series of land reform programs was enacted in Taiwan between 1949 and 1953. The farm rent reduction program was passed in 1949, the sale of public land in 1951, and the land-to-tiller act in 1953. The laws were designed to protect tenancy rights in both rent obligation and land acquisition. The maximum rent was fixed at 37.5 percent of the 1948 crop level. Tenants are given priority to purchase land from the landlord when it is on the market at 30–50% below the market value or in compensation.
2. Fujiki (1999) makes a similar observation on hired service or "contract" farming, and on its implication on rice production costs in Japan and in Taiwan. Since hired service in Japan is not as common as it is in Taiwan, small farmers in Japan tend to buy their own farm machinery and cultivate their own paddies. Consequently, excessive investment in farm machinery leads to high cost of production.
3. Lee (1978) first proposes a switching model with a criterion function in a study of union participation where wage differentials between union and nonunion sectors are the determinant. Willis and Rosen (1979) also consider the model in the context of education level and earnings.
4. We know of no other stochastic frontier application to the self-selection model in the literature even though there is a large literature on both stochastic frontier studies and self-selection modeling.
5. The maximum likelihood estimation is obviously distribution dependent and the estimated efficiency is sensitive to the distribution assumption of the one-sided error u_i. However, as Kumbhakar and Lovell (2000, p. 90) point out that "neither rankings nor compositions are particularly sensitive to distribution assumptions," and argue for the use of "a relative simple distribution, such as half normal or exponential."
6. The survey conducted for this study is aimed at 240,000 second (winter) crop rice farms operated in 1998, which is about $^3/_4$ of the first (summer) crop farms. Winter farming is less due to water shortages in the crop season. A stratified random sample of 400 farms is sampled from counties and townships. The sample size in each stratum or county is proportional to the percentage of rice acreage planted in that county to the total rice acreage planted in Taiwan.
7. For those 13%, hired-plowing farmers who own either tillers or tractors reveal that "lack of family labor" and "self-plowing is too hard to work" are the two main reasons for not doing the plowing themselves.
8. The hectare plowed, investment in tiller equipment, and plowing arrangement are naturally a joint decision in farming operation. However, the paper concerns only the plowing stage of farming operation. The modeling

of the decision on hired/self plowing is thus a partial analysis conditioned on the exogenously determined variables, HECTARE and TILLER. We acknowledge a referee's comment on this point.

9. The derivative of the probability of hired-plowing with respect to a particular variable is $\partial\Phi(z\gamma)/\partial z = \gamma\phi(z\gamma)$, where $\Phi(.)$ and $\phi(.)$ are probability and density, respectively, of hired-plowing and γ is the coefficient of z.
10. The marginal impacts on the probability of hired-plowing are 0.03 for EDU, 0.09 for AGE65, −0.01 for ln(HISE), and −0.16 for FY.

References

Aigner, D. J., C. A. K. Lovell and P. J. Schmidt. (1977). "Formulation and Estimation of Stochastic Frontier Model." *Journal of Econometrics* 6, 21–37.

Battese, G. E. and T. J. Coelli. (1988). "Prediction of Firm-Level Technical Efficiencies with a Generalized Frontier Production Function and Panel Data." *Journal of Econometrics* 38, 387–399.

Bera, A. K. and S. C. Sharma. (1999). "Estimating Prediction Uncertainty in Stochastic Frontier Production Function Models." *Journal of Productivity Analysis* 12, 187–210.

Fujiki, H. (1999). "The Structure of Rice Production in Japan and Taiwan." *Economic Development and Cultural Change* 47, 387–400.

Jondrow, J., C. A. K. Lovell, I. S. Materov and P. Schmidt. (1982). "On the Estimation of Technical Inefficiency in the Stochastic Frontier Production Function Model." *Journal of Econometrics* 19, 233–238.

Kumbhakar, S. C. and C. A. Knox Lovell. (2000). *Stochastic Frontier Analysis,* Cambridge University Press.

Lee, Lung-Fei. (1978). "Unionism and Wage Rates: A Simultaneous Equations Model with Qualitative and Limited Dependent Variables." *International Economic Review* 19, 415–433.

Olson, J. A., P. Schmidt and D. M. Waldman. (1980). "A Monte Carlo Study of Estimators of Stochastic Frontier Production Functions." *Journal of Econometrics* 13, 67–82.

Willis, R. J. and S. Rosen. (1979). "Education and Self-Selection." *Journal of Political Economy* 87(Pt. 2), 507–536.