# Measuring the effect of transaction costs for investment in irrigation pumps: Application of the unobserved stochastic threshold model to the case of Nigeria

HIROYUKI TAKESHIMA*

*International Food Policy Research Institute, Abuja, Nigeria*

ADETOLA I ADEOTI

*Department of Agricultural Economics, University of Ibadan, Nigeria*

SHEU SALAU

*International Food Policy Research Institute, Abuja, Nigeria*

This article empirically assesses the effect of unobserved transaction costs for Nigerian farmers when investing in irrigation pumps. The unobserved stochastic threshold (UST) model popularly used in labor economics literature is applied, and is compared with two models, the Tobit and the Heckman sample selection model, which are slightly more restrictive versions of the UST model. The results indicate that the unobserved transaction costs are higher for female farmers, landless farmers, those who have a comparatively high dependency ratio, and those who live far from town. The results suggest that the unobserved transaction costs can be as important as the factors determining the profitability of irrigation pumps, which emphasizes the importance of reducing transaction costs and providing the environment for higher returns from investment in irrigation. From a methodological perspective, the UST model is found to be more accurate and informative than the Tobit and Heckman models.

**Keywords:** transaction costs; unobserved stochastic threshold model; willingness to invest; irrigation pump; Nigeria

*Cet article évalue de manière empirique l'effet des coûts de transaction non observés lorsque les fermiers nigérians investissent dans des pompes d'irrigation. Le modèle stochastique à seuil non observé (UST en anglais), couramment utilisé en littérature traitant de l'économie du travail, est utilisé et comparé à deux autres modèles, le modèle de Tobit et le modèle de sélection d'échantillon d'Heckman, qui sont des versions légèrement plus restrictives que le modèle UST. Les résultats indiquent que les coûts de transaction non observés sont plus élevés pour les fermières, les fermiers sans terre, ceux qui montrent un taux de dépendance comparativement élevé, et ceux qui vivent loin des villes. Les résultats suggèrent que les coûts de transaction non observés peuvent être aussi importants que les facteurs déterminant la profitabilité des pompes d'irrigation. Ceci souligne l'importance de réduire les coûts de transaction et de fournir l'environnement de sorte que l'investissement en irrigation génère plus de revenus. D'un point*

* Corresponding author: H.Takeshima@cgiar.org

*de vue méthodologique, le modèle UST se révèle plus exact et plus informatif que les modèles de Tobit et d'Heckman.*

***Mots-clés :*** *coûts de transaction ; modèle stochastique à seuil non observé ; volonté d'investir ; pompe d'irrigation ; Nigéria*

## 1. Introduction

In Nigeria, small-scale private irrigation schemes (SPRIs) have reportedly been more successful than publicly operated large-scale schemes. The SPRI is popular among farmers, particularly because it allows for adjustment of irrigation schedules in accordance with observed crop needs (Dauda et al., 2009). Among the many private kinds of irrigation equipment, modern water-lifting devices are essential for expanding the planted area, raising the yield of certain crops and allowing some farmers to undertake dry season production of food and cash crops.

To lift water, farmers commonly use a shadoof, treadle pump or motorized pump. Although the performance of these tools varies, typically a motorized pump can irrigate 1 ha of land, a treadle pump 0.2 to 0.5 ha and a shadoof less than 0.1 ha (Omilola, 2007). The shadoof is very laborious and time consuming to use, and relatively inefficient because of its low discharge and flow rates. Pumps are more suitable for irrigating large farms. The relative success of private irrigation schemes in Nigeria indicates that farmers can benefit significantly from investing privately in various irrigation equipment, including irrigation pumps.

Only a small fraction of farmers, however, currently own a pump. Even in the 12 states that participated in the Second National Fadama Development Project (Fadama II), where both surface and underground sources of water are relatively accessible, only about 12% have their own pump and 5% own a pump as a group (Fadama II dataset), although adoption of engine-driven irrigation pumps is becoming common in certain parts of Nigeria (Pasquini et al., 2004).

There is a broad range of reasons why the level of observed investment in irrigation pumps is low. Farmers may simply lack access to finance. Their source of water may be unreliable. Fuel costs may be high. They may not know how to maintain a pump and they may be reluctant to make the investment. Further, even though their willingness to invest (WTI)[1] may be high, they may be discouraged by the high transaction costs involved (i.e. the costs of organizing an economic system, Arrow, 1969). Farmers in Africa face the same kind of fixed transaction costs as those associated with participating in the market, such as comparing prices, obtaining information about the quality of particular types of pumps, and the time and transport costs associated with purchasing (discussed in more detail below). As transaction costs are often associated with market failure, the government or the public sector has a comparative advantage in reducing such costs. This, however, is not easy, as the costs are farmer specific, observable only to each farmer, and cannot always be measured in monetary terms.

[1] More explicitly, WTI in this paper is defined by equation (8) in the conceptual framework.

This article attempts to relate unobservable transaction costs to observable characteristics of farmers. More specifically, it assumes that transaction costs translate to a threshold, or minimum required investment level, for a farmer to be willing to invest, i.e. to feel justified in incurring the fixed transaction costs of investing in an irrigation pump. Although the thresholds are unobservable and farmer-specific, as are the transaction costs, they are comparable to the WTI.

The article deals with two research questions. First, applying the unobserved stochastic threshold (UST) model (Nelson, 1977; Cogan, 1981) to the dataset collected to evaluate the Fadama II project, this article empirically examines whether some of the observable household characteristics affect or do not affect the thresholds, and by how much if they do. Second, it assesses how the UST model improves on two other simpler and popular but more restrictive models, the Tobit model (Tobin, 1958) and the Heckman model (Heckman, 1979), which also incorporate the unobserved farmer-specific thresholds. The more technical discussions are provided in Section 5.

The contribution to the literature is as follows. First, the article provides an empirical example to illustrate the effects that high transaction costs in sub-Saharan Africa have on farmers' decisions to invest in irrigation equipment. It does this by identifying factors that affect such transaction costs and, within certain assumptions, the magnitude of the effects. Although other studies have discussed the issues of transaction costs associated with investment, they have yet to provide empirical estimates to substantiate their conclusions. Second, the article employs a methodology widely used in the labor economics literature but less commonly used in the agricultural economics literature, despite its potential to provide information on the nature of transaction costs and their effects on farmers' investment decisions.

## 2. The Fadama II project

Fadama II is one of the World Bank and African Development Bank assisted agricultural development programs aimed at addressing productivity growth constraints in Nigeria. It operates on the concept of community driven development (CDD), a bottom-up approach that emphasizes social cohesion or more inclusiveness in the management of community resources and governance. Pilot asset acquisition is one of its key components and it covers assistance for purchasing a moderately priced irrigation pump and other equipment for enhancing productivity growth and value added activities. The Fadama II dataset was chosen for this study as it contains rich information on farmers' investment behavior and other socio-economic characteristics (NFDC, 2006).

## 3. Transaction costs associated with irrigation pump investment in Nigeria

Many of the transaction costs that semi-subsistence farmers face when participating in the market (Key et al., 2000) are due to the costs of obtaining information, liquidity constraints, or the absence of laws or regulations that protect the rights of both farmers and pump sellers, or the non-enforcement of these laws or regulations. These factors also apply to transaction costs associated with investment in irrigation pumps. Conditions observed in Nigeria suggest that these costs exist.

A pump has considerable resale value, so it is an important personal investment and thus the transactions associated with it may be individual-specific. Transaction costs in irrigation pump investment in Nigeria are often represented by travel time, transport costs, the costs involved in searching for the desired model and quality, and the cost of obtaining information about the operation of the pump.

Farmers have to spend time searching for service providers and pump sellers, who are generally to be found in cities such as Kano and Abuja. They must travel long distances, particularly if they come from deep rural areas, to increase their options and make sure they get the right model at the right price. Their travel time costs can be substantial, depending on the type of transport (motor bike, bus or car), the condition of the roads, the amount of traffic and the distance of the farm from the sellers. Time is spent in searching for particular models on the open market, looking for a competitive price, and checking the quality of the pumps on offer. These costs are compounded if there are repeat visits, for example if the trusted seller is out of stock, the model is not available or the farmer is not satisfied with the performance of the pump and has to return it.

The cost of learning to operate the pump may be less substantial, as extension workers, Fadama office facilitators, international NGOs, pump sellers and other farmers are available to demonstrate the pumps and explain how to operate them. However, this may be different for female farmers. For example, in Hausa culture, managing irrigation has been predominantly a male activity (Salisu, 2001) and since women may find it difficult to communicate with their male counterparts, this could lead to higher transaction costs for them.

## 4. Estimation of threshold determined by transaction costs

There is a large literature on investment in the presence of high fixed transaction costs. Several studies have modeled the determinants of demand for durable production assets in the presence of certain types of market failure (Rosenzweig & Wolpin, 1993). With respect to the agricultural sector, Heckman's (1979) model and its variants have been widely applied to explain semi-subsistence farmers' market participation decisions where high transaction costs are associated with the decisions (Goetz, 1992; Heltberg & Tarp, 2002). Few studies, however, have assessed the actual size of transaction costs, or the threshold level that is determined by these costs, when making decisions on investment or market participation (Renkow et al., 2004), except when the costs are assumed to be observable (Mburu et al., 2008). Moreover, the model used by Renkow et al. (2004) requires a rather intensive computation.

One of the most popular models for assessing the size of transaction costs and the threshold level is the unobserved stochastic threshold (UST) model used by Nelson (1977), Cogan (1981) and Maddala (1983), which has long been applied to analyzing workers' labor market participation decisions and estimating threshold levels. However, the UST model has not often been used in the agricultural sector. Key et al. (2000) have used it to analyze farmers' market participation decisions in Kenya.

*4.1 Demand factor for small-scale irrigation technologies and adoption decisions by farmers*

An agricultural household faces the following utility maximization problem, which is modified from Key et al. (2000) and Bellemare & Barrett (2006).

$$\max_{I_t, s_t} \quad \sum_{t=0}^{\infty} u_t(c_{kt}; z_u) \cdot \delta^t \tag{1}$$

subject to

$$\sum_{k=1}^{K} p_{kt} m_{kt} + T_t + W_t - s_t \geq 0 \tag{2}$$

$$q_{kt} - x_{kt} + A_{kt} - m_{kt} - c_{kt} \geq 0, \quad \text{for all } k = 1,2 \ldots, , \ldots, k \tag{3}$$

$$W_{t+1} = W_t - \sum_{I} \tau_t(z_\tau) \cdot I_t \tag{4}$$

$$G(q, x, S_t; z_q) = 0 \tag{5}$$

$$c_{kt}, q_{kt}, x_{kt}, s_t \geq 0 \tag{6}$$

in which the household's utility at time $t$ ($u_t$) is a function of consumption of $k$-goods ($c_k$) and other factors $z_u$. The utility is a sum of future utility discounted with factor $\delta$. $I_t$ is the discrete variable, which equals 1 if a farmer invests/ does not invest in irrigation equipment at period $t$ and 0 otherwise.

Equation (2) states the cash or budget constraint, in which the sum of net revenue from market trading of goods $k$ , which equals the price of goods $k$ at $t$ ($p_{kt}$) times net sales quantity ($m_{kt}$), external income received at $t$ ($T_t$) and the unproductive liquid asset at the beginning of period $t$ ($W_t$) will not be less than the amount invested for an irrigation pump at time $t$ ($s_t$).

Equation (3) states the resource balance, in which for each good $k$ the quantity produced ($q_{kt}$) plus net sales ($m_{kt}$) or supply from initial endowment ($A_{kt}$) should not be less than the quantity consumed ($c_{kt}$) and the quantity used as inputs ($x_{kt}$).

Equation (4) states that at the beginning of $t$ a farmer must have enough liquid asset to cover the fixed transaction costs ($\tau_t$ ($z_\tau$), which is assumed to be a function of factors $z_\tau$) associated with irrigation pump investment if he/she invests.

Equation (5) states the production technology which defines the relationship between the output $q$ and inputs $x$ as well as the irrigation investment level at $t$ ($S_t$) and other factors $z_q$.

To solve the utility maximization problems (1) through (6), this article follows a seminal paper, Rosenzweig & Wolpin (1993), which presents a similar model for farmers' pump investment in India and applies Bellman's equation (Bellman, 1952)[2] to the expected lifetime utility function.

Modifying Rosenzweig & Wolpin (1993), the expected lifetime indirect utility function can be derived from (1) through (6) as:

$$V_t\left(z_q, p_{kt}, S_t, s_t, \tau_t, \varepsilon_t\right) = \max_{s_t}\{u_t\left(c_{kt}(s_t)\right) + \delta \cdot E\max\left[V_{t+1}\left(W_{t+1}, A_{k,t+1}, T_{t+1}, z_{q,t+1}, p_{k,t+1}, S_t + s_t, \tau_t, \varepsilon_{t+1}\right)\right]\} \quad (7)$$

which assumes that all the arguments in the indirect utility function (7) change between $t$ and $t$+1 only due to the decisions on $s_t$ or idiosyncratic factors that are beyond farmers' control. Then the optimal level of $s_t$ ($s_t$*) can be expressed as a function of observed characteristics at $t$ alone as in (8):

$$s_t^* = f\,(W_t, A_{kt}, T_t, z_q, p_{kt}, S_t, \varepsilon_t) \quad (8)$$

and therefore the subscript $t$ is dropped from the subsequent discussions.

We now focus on the unobserved threshold regarding the willingness to invest (WTI) $s^*$ in (8). The utility maximization problem here specifies that the farmer incurs fixed transaction costs $\tau = \tau'$ in investing. As $\tau$ is independent of the level of $s^*$, only farmers with significantly high $s^*$ accept to incur $\tau'$ and actually invest $s^*$ and farmers with lower $s^*$ are less likely to incur $\tau'$ and invest $s^*$. A key question in this article is how a policy can reduce $\tau$ so that more farmers will decide to incur $\tau$ and invest $s^*$.

More specifically, the threshold level is determined in the following way. From (7), we define the indirect utility function $V$ for the case of making investment ($V_Y$) and not making investment ($V_N$);

$$V_Y = V(z_q, p_k, S, s, \tau, \varepsilon \mid s = s^*, \tau = \tau' > 0) \quad (9)$$

$$V_N = V(z_q, p_k, S, s, \tau, \varepsilon \mid s = 0, \tau = 0) \quad (10)$$

We assume that a farmer makes irrigation investment if $V_Y \geq V_N$ and does not invest if otherwise. Suppose that $V(z_q, p_k, S, s, \tau, \varepsilon)$ is an increasing function of $s$, and let $s'$ be the threshold level of investment at which the corresponding benefit is equal to the transaction cost of investment:

$$V_Y\,|_{\,s=s'} = V(z_q, p_k, S, s, \tau, \varepsilon \mid s = s^* = s', \tau = \tau') = V(z_q, p_k, S, s, \tau, \varepsilon \mid s = 0, \tau = 0) = V_N \quad (11)$$

Then a farmer's decision-making mechanisms on whether to invest in an irrigation pump can be simplified to the comparison between $s^*$ and $s'$, such that,

[2] Bellman's equation essentially states that the dynamic optimization problems can often be reduced to the optimization at the first period.

$$\begin{aligned} &\text{invest } s^* \text{ if} && s' \leq s^* \\ &\text{does not invest if} && s' > s^*. \end{aligned} \tag{12}$$

*4.2 The effects of observable and unobservable fixed costs*

Figures 1 through 3 illustrate the theoretical model outlined above using a simplified version of Cogan's (1981) presentation using indifference curves. For simplicity, we assume that the farmer's utility $V$ is determined by two factors, (1) the initial resources available for irrigation investment or other uses such as consumption (denoted as $H$ and measured in horizontal axis in Figure 1), and (2) the value generated from all economic activities plus the initial endowment of such values (denoted as $Y$ and measured in vertical axis in Figure 1). We drop subscript $t$ because the utility maximization problem is now static, as expressed in equation (8).

In Figure 1, the point $E^0$ is the initial point for a farmer in which he/she is endowed with $h_0$ amount of resources $H$ that can be either used to buy an irrigation pump or simply consumed. Without allocating some of $h_0$ to investing in the pump, the farmer realizes $y_0$ from his/her all economic activities. $\tau$ represents the total fixed cost of making the investment. The farmer now decides whether to invest a certain amount of $H$ in the pump, or to consume the total amount. If the farmer decides to invest $h_0 - h_1$ of $H$ in the pump, this investment provides a return of $y_1 - y_0$, and the combination of $H$ and $Y$ moves to $E^1$, which realizes a utility level $V^1$, which is higher than $V^0$. The utility function represented by the indifference curve $V^0$ is assumed to be quasi-linear (this will enable the assumption that a higher marginal benefit always leads to more investment).

To facilitate the interpretations of the succeeding estimation results, first we assume that the utility function is quasi-linear in the direction of the $y$-axis (overall return such as value of crops, including returns from irrigation), so that the marginal rate of substitution is constant given the resources available for the pump. This assumption implies that an increase (decrease) in the marginal benefit of the pump increases (decreases) the willingness to invest in the pump. Second, we assume that the transaction costs ($\tau$) are measured by the vertical distance as in Figure 1.[3]

With the above assumptions, Figures 2 and 3 illustrate how the WTI and threshold WTI are determined by the initial endowment ($E^0$), marginal benefit of the pump ($\pi$), and fixed transaction costs ($\tau$); how only the WTI higher than the threshold WTI is actually invested (Figure 2); and how the reduction in $\tau$ lowers the threshold WTI (Figure 3). The relationships between actual WTI, threshold WTI and $\tau$ illustrated in Figures 2 and 3 allow us to use the stochastic threshold model and derive some policy implications for reducing the transaction costs.



[3] This assumption therefore separates the resources available for investing into the cost of the irrigation pump and the transaction costs. In this paper the effect of transaction costs is therefore measured by the reduction in overall return measured by the vertical axis.

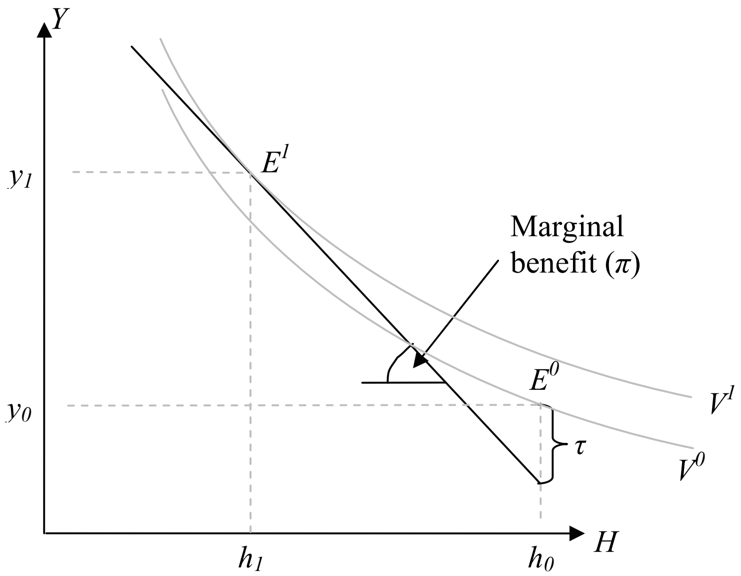


**Figure 1: Simplified version of Figure 1 (a) in Cogan (1981)**

*Notes:*

*Y* : Value of all economic activities (including the return to the investment of irrigation pumps) (assume that transaction costs affect this, not *H*)

*H* : Initial resource available for irrigation investment (or other uses)

*τ* : transaction costs of making investment

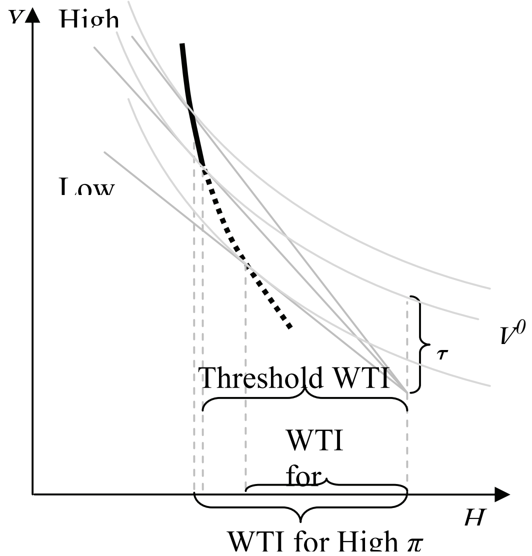


**Figure 2: Threshold WTI, and range of irrigation investment level in the presence of transaction costs**

*Notes:*

The threshold WTI ($s'$) and **the threshold return level $\pi$*** are jointly determined by:

- Initial endowment ($E^0$)
- Indifference curve ($V^0$)
- Fixed transaction costs ($\tau$)

Farmer's WTI is determined by $\pi$. With a high $\pi$, a higher utility than $V^0$ is reached, so the farmer invests.

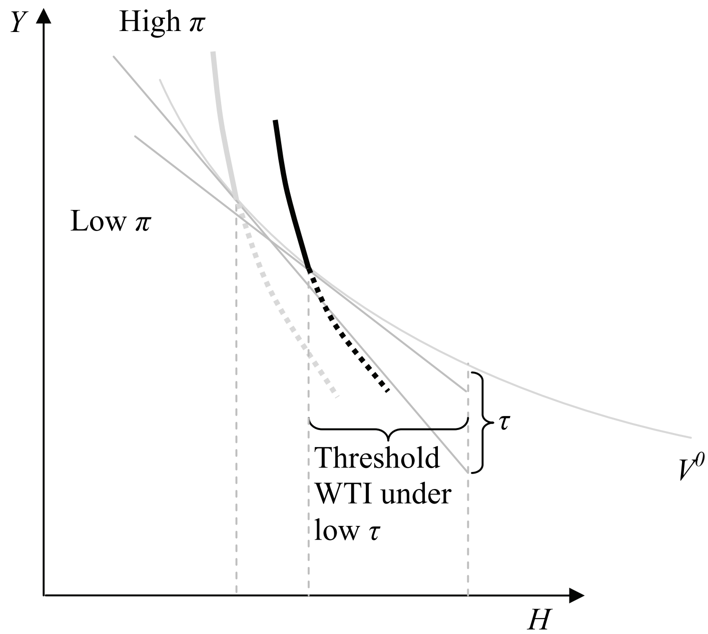


**Figure 3: Reduction in transaction costs $\tau$ and the effect on threshold WTI**

*Notes:*

The reserved investment level $s$* and **the threshold return level $\pi$*** are jointly determined by:

- Initial endowment ($E^0$)
- Indifference curve ($V^0$)
- Fixed transaction costs ($\tau$)

Farmer's WTI is determined by $\pi$. With a high $\pi$, a higher utility than $V^0$ is reached, so the farmer invests.

In addition, we also assume that the farmer knows about the return per irrigation investment or has at least some idea about the return, given the level of investment, as he/she may be able to get such information relatively inexpensively from other farmers. This article thus distinguishes the information on return per irrigation investment from other information on location of sellers of particular types of pumps, or the quality of particular types of pumps, as discussed above.

This series of assumptions is made since the primary purpose of this article is to estimate the effects of transaction costs, including those associated with obtaining certain types of information other than the information on return per investment. The follow-up studies to this article will relax some of the aforementioned assumptions in analyzing the transaction costs of irrigation pump investment.

The empirical analysis in Sections 5 and 6 below is based on the assumption (12), in which $s^*$ is observed only for those who actually invest, and $s'$ is unobserved for all farmers. This is illustrated in Figure 4.

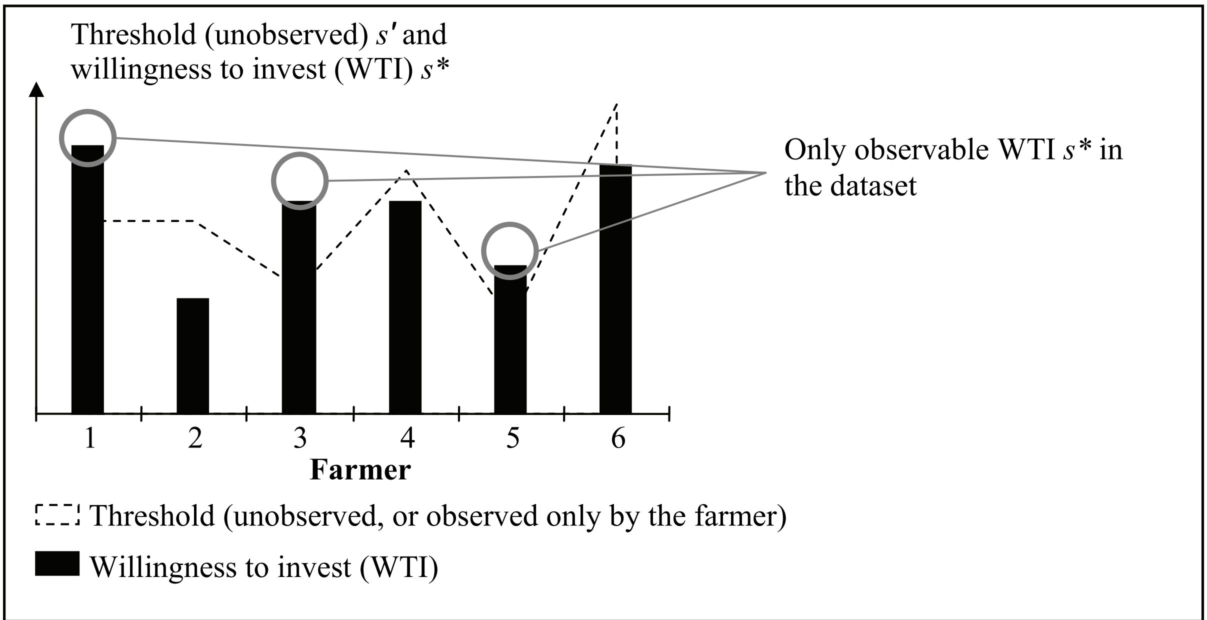


**Figure 4: WTI, unobserved threshold and observed investment level**

## 5. Empirical methodology and data

Following Cogan (1981) and Nelson (1977) and Maddala (1983), we use the notations $s_{i1}$ as $s^*$ (WTI) in (8) and $s_{i2}$ as $s'$ (threshold) in (12) and assume they are linear functions of observed characteristics:

$$s_{i1} = \alpha_1 + \beta_1 \cdot X_i + \gamma_1 \cdot z_{i1} + \varepsilon_{i1} \quad (13)$$

$$s_{i2} = \alpha_2 + \beta_2 \cdot X_i + \gamma_2 \cdot z_{i2} + \varepsilon_{i2} \quad (14)$$

$$\begin{pmatrix} \varepsilon_{i1} \\ \varepsilon_{i2} \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_1 & \rho_{12} \\ \rho_{12} & \sigma_2 \end{pmatrix}\right) \quad (15)$$

in which $\varepsilon_{i1}$ and $\varepsilon_{i2}$ follow the joint normal distribution with correlation $\rho_{12}$. The requirement for the identification is that there is at least one exogenous variable $z_{i1}$ in (13) that does not appear in (14) (Maddala, 1983; Nelson, 1977). The threshold ($s_{i2}$) in the UST model can be interpreted as the reservation value of the resource for alternative use. With $s_1$ and $s_2$, we observe

$$\begin{aligned} s_i &= s_{i1} \quad \text{if } s_{i1} > s_{i2} \\ s_i &= 0 \quad \text{otherwise} \end{aligned} \quad (16)$$

While the UST model is often estimated using the maximum likelihood estimation (MLE) method, this article uses the two-step estimation method proposed by Maddala (1983), which is still consistent although less efficient than the MLE method if the normality assumption holds. The MLE method is, however, generally more sensitive to the normality assumptions and can be very poor if the assumption is violated (Murphy & Topel, 1985). In addition, the MLE method is computationally cumbersome and it is usually very difficult to distinguish local maxima from the global maximum and the estimation using this method is also sensitive to the initial values used. Estimations were done using Stata 10.

Although the focus of this article is the estimation of the threshold, it is also beneficial to see how the estimation of WTI is improved when using the UST model rather than other alternative estimation methods that employ more restrictive assumptions but are simpler and more widely used. Popular alternatives to the UST model, among others, are the Tobit and the Heckman sample selection model. Both these models share common features with the UST model, as they explore the unobserved thresholds and incorporate their effect into the estimation of WTI. The UST model exploits more information from the dataset than the Heckman and Tobit models, while the Tobit model adds more restrictions to the Heckman model and the Heckman model adds more restrictions to the UST model, as described below in (17) through (22). The UST model, however, is usually unavailable in commercial software, including Stata, unlike the Heckman and Tobit models, and thus it is informative to see how the UST model improves on the Heckman and Tobit models.

Heckman follows similar structure to the UST model except that in the Heckman model a latent variable $s_H$ is defined in the place of $s_{i2}$,

$$s_{i1} = \alpha_1 + \beta_1 \cdot X_i + \gamma_1 \cdot z_{i1} + \varepsilon_{i1} \tag{17}$$

$$s_{iH} = \alpha_H + \beta_H \cdot X_i + \gamma_H \cdot z_{iH} + \varepsilon_{iH} \tag{18}$$

$$\begin{pmatrix} \varepsilon_{i1} \\ \varepsilon_{iH} \end{pmatrix} \sim N\left( \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_1 & \rho \\ \rho & 1 \end{pmatrix} \right) \tag{19}$$

and

$$\begin{aligned} s_i &= s_{i1} \quad \text{if } s_{iH} > 0 \\ s_i &= 0 \quad \text{otherwise} \end{aligned} \tag{20}$$

The Heckman model is more restricted than the UST model. In order to see it, rewrite (16) as

$$\begin{aligned} s_i &= s_{i1} \quad \text{if } s_{i2} < s_{i1} \\ s_i &= 0 \quad \text{otherwise} \end{aligned} \tag{16$'$}$$

While the censoring rule in the UST model is $s_{i2} < s_{i1}$, the rule in the Heckman model is $s_{iH} > 0$. The Heckman model is more restrictive than the UST model because it forces the censoring threshold at 0.

In the Tobit model, $s_{i1}$ is the only latent variable and,

$$s_{i1} = \alpha_1 + \beta_1 \cdot X_i + \gamma_1 \cdot z_{i1} + \varepsilon_{i1} \tag{21}$$

in which

$$\begin{aligned} s_i &= s_{i1} \quad \text{if } s_{i1} > 0 \\ s_i &= 0 \quad \text{otherwise} \end{aligned} \tag{22}$$

In other words, the Tobit model adds an additional restriction of $s_{i1} = s_{iH}$ to the Heckman model.

In the context of farmers' irrigation investment decisions, the additional restrictions of the Tobit and Heckman models, which are absent in the UST model, have the following consequences. The Tobit model assumes that the factors that lower (raise) the threshold levels also increase (reduce) the WTI. The UST and Heckman models are free from this assumption. The Heckman model assumes that the linear combination of observed characteristics relates to the probability of farmers exceeding the threshold, while the UST model assumes that the same linear combination directly measures the thresholds themselves. Generally, the Heckman model can give a good prediction of the qualitative results obtained in the UST model (for example the sign and significance of estimated coefficients for the threshold in the UST model can be easily predicted from the same coefficients estimate in the selection equation in the Heckman mode), but not the quantitative results, which are informative in assessing the gap between the farmers' WTI and the thresholds they face.

The variables $X_i$ , which are expected to affect both the WTI and the threshold, include general characteristics of the respondent (age, gender, years of education) and household characteristics (dependency ratio, household size; total household expenditure in 2005 and total asset value in 2006, whether the household owns part of their land, whether the household received credit in 2005, and total rainfed area owned), access to basic infrastructure (distance to nearest town and all-weather roads), membership (whether the farmer is a Fadama II member, or a Fadama II neighbor, i.e. a non-Fadama II member within a Fadama II LGA, or a non-Fadama II LGA farmer, i.e. a non-Fadama II member within a non-Fadama II LGA),[4] whether the farmer belongs to a cooperative or other farmer association), access to water management facilities (whether the farmer currently has access to any type of irrigation facility, borehole or concrete well), the crop area where irrigation is commonly applied (area planted for each of pepper, rice, sugarcane and tomato in 2005) and dummy variables for state (i.e. division of Nigeria).

The variable $X_i$ also includes variables in which Fadama II membership is combined with rainfall and rainfall risks. The average rainfall and rainfall risks are included because Fadama II members (and to some extent Fadama II neighbors) face fewer liquidity constraints for irrigation pump investment, so rainfall level and risks become more important factors for them when deciding whether to invest in irrigation technology (Koundouri et al., 2006; Phillip et al., 2009), while for other farmers liquidity constraints are more important factors than the rainfall conditions. Including rainfall data as interaction terms also avoids perfect multicollinearity with state dummy variables (rainfall data are available only at the state level).

[4] An LGA is a local government area, an administrative unit/ sub-district within each state in Nigeria.

Rainfall data (the historical average of annual rainfall and coefficient of variation of that annual rainfall) are obtained for locations near each state (Table 1). The significantly higher difference is observed in the coefficient of variation between cities, indicating a possibility of heterogeneous WTIs across regions due to varying rainfall risks. Risk associated with irrigation technology is another source of costs for farmers as it affects the amount of information they require about how to operate the pump and how it will affect their future yield and output.

The total value of an irrigation pump in 2005 is used for variable $z_{i1}$. Although farmers who have already invested in a pump may be less willing to invest in 2006 (and this affects the WTI), the level of their investment may not affect their threshold.[5] This is because, as explained in Section 2, the transaction costs are made up mostly of transport and repeat visits to negotiate the price, and thus are independent of their irrigation pump investment level in 2005. (The farmer has to incur the same transaction costs again – traveling to the store, negotiating the price, repeat visits etc. – if he wants to buy a second pump.) Similarly, $z_{i2}$ is captured by the availability of financial assistance other than from Fadama II, which is indexed by whether the farmer received this assistance for buying the pump before or after Fadama II was implemented.[6] The availability of other financial assistance can lower the threshold, but does not affect the WTI.

After dropping the data with missing variables, a total of 2232 observations were used in the analysis, of which 160 households personally invested in irrigation pumps in 2006 (i.e. not as a group investment). The households in the dataset are typical sub-Saharan African rural households, with a low education level, low expenditure level, and located far from towns and main roads (Table 2). Most of the farmers who invested in irrigation pumps in 2006 are male, own at least part of the land they cultivate, and are members of the Fadama II project.

Approximately 14% of Fadama II members (118 of the 804 farmers in the dataset) invested in irrigation pumps using financing from Fadama, while the two categories of non-members invested in pumps using other finance sources (Table 3). Interestingly, while the proportion of male farmers who invested in irrigation pump is slightly larger than that of female farmers, the women generally invested more than the men (Table 4), indicating that while the women may be as willing to invest as the men, or even more willing (i.e. they have the same or even higher WTI), they face higher transaction costs that raise the minimum required investment level.

The dataset also shows that irrigation is most widely used for pepper, rice, sugarcane and tomato. The areas planted for these four crops in 2005 can be good proxies for farmers' willingness to invest in a pump, and may also affect their exposure to irrigation technologies and thus the threshold level. As Table 2 shows, the percentage of farmers growing these crops is higher

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[5] Some farmers buy a second irrigation pump so they can irrigate two distant plots at the same time.

[6] Although the existence of such assistance is observed only if a farmer actually invested in a pump using such assistance, it is believed to be a fairly good indicator of the availability of such assistance, which leads to the assumption that this variable is not endogenous to the farmer's investment decision. This is because some of this assistance, for example the SPFS (Special Program for Food Security), provides pumps virtually for free, in which case a farmer has no reason not to receive a pump. The type of pump is, however, limited and thus such assistance does not affect a farmer's WTI. Moreover, the scale of operation by SPFS is smaller than Fadama II and thus the impact of Fadama II on farmers' investment in irrigation pumps is still expected to be significant even in the presence of assistance other than from Fadama II.

among those who had newly invested in a pump in 2006, and the areas planted are usually more than 1 ha.

Overall, the descriptive statistics indicate a possibly systematic variation in the unobserved threshold levels across individual households. The empirical analysis using the UST model can provide quantitative information about such variation that is not immediately clear from the descriptive statistics.

The issues of self-selection and estimation bias are concerns when using dummy variables for Fadama II membership, as evidenced by many studies, such as Nkonya et al. (2008), which employ more sophisticated methods to evaluate the benefits of Fadama II. This article, however, assumes that the dummy variables for Fadama II consistently capture their effect on farmers' WTI and threshold, since our focus is on linking farmers' investment behaviors with unobserved transaction costs and the estimation becomes quite complicated if the issue of self-selection needs to be considered. Future studies need to consider the effect of combining the issues of unobserved transaction costs and farmers' self-selection for membership of Fadama II.

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**Table 1: Statistics from historical rainfall data in various locations**

| State | Reference city | Average annual rainfall | Coefficient of variation |
|---|---|---|---|
| Adamawa | Yola | 900 | .3329 |
| Bauchi | Bauchi | 1002 | .1657 |
| Gombe | Bauchi | 1002 | .1657 |
| Imo | Owerri | 2362 | .1296 |
| Kaduna | Kaduna | 1200 | .1204 |
| Kebbi | Sokoto | 628 | .2107 |
| FCT | Abuja | 1458 | .0955 |
| Lagos | Ikeja | 1523 | .1575 |
| Niger | Minna | 1202 | .1404 |
| Ogun | Ijebu Ode | 1611 | .1504 |
| Oyo | Ibadan | 1352 | .2038 |
| Taraba | Yola | 900 | .3329 |

*Source:* Data calculated by the authors from NIMET (2009), except for Adamawa and Taraba, where the data is from Oyekale (2009).

**Table 2: General household characteristics (US$ with conversion rate of US $1 = 127 Naira)**

| | **All observations (observation = 2232)** | | **Those who invested in an irrigation pump in 2006 (observation = 160)** | |
|---|---|---|---|---|
| | median | std.dev | median | std.dev |
| Household size | 8 | 7 | 10 | 6 |
| Age of respondent | 42 | 12 | 45 | 12 |
| Female respondent (%) | 29 | 0.5 | 17 | 3 |
| Dependency ratio | 1 | 7 | 1 | 2 |
| Years of education of respondent | 6 | 6 | 6 | 6 |
| Total expenditure (US$) | 281 | 2925 | 224 | 492 |
| Total value of asset (US$) | 2521 | 429134 | 3209 | 14981 |
| Distance to nearest town (km) | 5 | 20 | 4 | 8 |
| Distance to all-weather road (km) | 3 | 103 | 2 | 240 |
| Received credit in 2005 (%) | 14 | 0.7 | 20 | 3 |
| Fadama II member (%) | 36 | 1.0 | 88 | 3 |
| Fadama II neighbor (%) | 36 | 1.0 | 8 | 2 |
| Non-Fadama II LGA farmer (%) | 28 | 1.0 | 4 | 2 |
| Own land (%) | 65 | 1.0 | 81 | 3 |
| Total area of land owned (ha) if own | 1.2 | 40687 | 3 | 7 |
| Total area of rain-fed land owned (ha) | 1.0 | 40633 | 2 | 5 |
| Have access to irrigation facility (%) | 2 | 0.3 | 14 | 3 |
| Have access to borehole (%) | 19 | 0.8 | 28 | 3 |
| Have access to concrete well (%) | 13 | 0.7 | 14 | 3 |
| Area planted for pepper (2005, ha) | 39 | 9115 | 301 | 10750 |
| % of those growing pepper | 7 | 0.5 | 17 | 3 |
| Area planted for rice (2005, ha) | 2 | 5112 | 2 | 7391 |
| % of those growing rice | 25 | 0.9 | 40 | 4 |
| Area planted for sugarcane (2005, ha) | | 2918 | 2 | 4556 |
| % of those growing sugarcane | 27 | 0.9 | 43 | 4 |
| Area planted for tomato (2005, ha) | 1 | 5 | 1 | 3 |
| % of those growing tomato | 30 | 0.9 | 49 | 4 |
| Member of cooperative (%) | 20 | 0.8 | 19 | 3 |
| Member of other farm organization (%) | 24 | | 11 | 2 |
| Value of irrigation pump in 2005 (US$) | 236 | 868 | 283 | 1033 |
| % who had irrigation pump in 2005 | 7 | | 24 | 3 |

*Note:* The median and standard deviations for area planted for the four crops are for those who grow these crops.

**Table 3: Investment in irrigation pump in 2006 by Fadama II membership**

| | **Fadama** II **financed** | **Other sources of finance** | **All (not the sum of the two)** |
|---|---|---|---|
| Fadama II member | 118 / 804 | 22 / 804 | 140 / 804 |
| Non-Fadama II member within Fadama II LGA | 0 / 796 | 12 / 796 | 12/ 796 |
| Non-Fadama II LGA farmer | 0 / 632 | 8 / 632 | 8 / 632 |

**Table 4: Investments in irrigation pumps in US$**

| | Obs | mean | median | min | max |
|---|---|---|---|---|---|
| Irrigation pumps | 160 | 545 | 238 | 0.08 | 7244 |
| Male farmer | 133 | 452 | 238 | 0.08 | 3937 |
| Female farmer | 27 | 989 | 393 | 71 | 7244 |

*Note:* US$ with conversion rate of US$1 = 127 Naira

Whether Fadama II members buy an irrigation pump or not may also be affected by other members' interests.[7] It is possible that other farmers' transaction costs may affect the decisions of some of them not to buy a pump through Fadama II. This article, however, assumes that the UST model can fairly accurately represent the effect of transaction costs on farmers' decision-making here, and the development of a model that reflects such complex decision-making structure is left for future study.

[7] This is because of the way Fadama II members decide to buy an irrigation pump. In Fadama II, farmers may obtain the pump in the following ways: a farmer can first decide whether to participate in a Fadama User Group (FUG), based only on their readiness to contribute own funds to various activities agreed by the member and carried out by the group, including the purchase of a pump at a subsidized cost. Pumps can be therefore purchased through Fadama II funds only if this is a unanimous decision of the members of the particular FUG. Once all members of the group have agreed, they buy the pumps as a group, or individually by receiving a 70% subsidy on the price of the pump, or up to $5000 for the entire group. The pumps are sold through advertisement to prospective suppliers and a bidding process. In principle, each farmer in the group can obtain a different type of pump based on individual need. The process of acquiring pumps can be time-consuming and is assumed to vary widely across the state or regions within the state.

Aside from pump acquisition, Fadama II provides various other benefits to FUGs which may affect the return on investment for pumps, including advisory services on production, processing, storage and marketing, although farmers do not have to buy a pump to receive these services. Specific to irrigation, the group benefits from advisory services on water management, water conveyance systems and maintenance of a pump. Various other types of grants or financial support for obtaining pumps have been available in Nigeria since the 1980s (Goes, 1999). Several other programs, such as the SPFS, encourage private farmers to invest in and use pumps, but with a different approach. Under the SPFS, pumps are bought and distributed to farmers who need them and the cost is recovered. While Fadama II provides some sort of subsidy, the SPFS only facilitates.

## 6. Results and interpretation

The preliminary results, presented in Tables 5 and 6, indicate that the threshold is as much correlated with observable characteristics as the WTI is, and thus any policy affecting farmers' transaction costs in investment is as important as increasing the marginal return from investing in an irrigation pump. In addition, the results from the UST and the Heckman models seem quite different from those of the Tobit model, indicating that the Tobit may not be appropriate for estimating the relationship between farmers' characteristics and their WTI.

**Table 5: Results from conventional models (results of state dummies are omitted)**

| | Selection | WTI (1000 Naira) | | | | | |
|---|---|---|---|---|---|---|---|
| | Marginal effect | OLS | | Tobit | | Heckman | |
| | | Coefficient | Std.err | Coefficient | Std.err | Coefficient | Std.err |
| Total value of irrigation pump in 2005 | 2.36e-08 | .356** | (.175) | .618*** | (.119) | .365*** | (.107) |
| Age | -.0002 | -.933* | (.416) | -1.091 | (.771) | -1.014** | (.430) |
| Household size | .0002 | -.464 | (.806) | -.271 | (1.499) | -.335 | (.851) |
| Gender of respondent (female = 1) | -.014** | 14.121 | (13.879) | -72.557*** | (20.063) | 9.013 | (13.795) |
| Education of respondent (years) | -.0003 | .305 | (.845) | -1.322 | (1.580) | .222 | (.928) |
| Dependency | -.001 | 2.555 | (2.334) | -5.385 | (4.690) | 2.386 | (2.126) |
| Total expenditure of 2005 (1 / 10,000) | -.375e-08** | .116 | (.084) | -.127 | (.083) | .106 | (.098) |
| Total value of asset (Naira) | -.924e-11 | .008 | (.007) | .000 | (.001) | .008** | (.003) |
| Land ownership (own = 1) | .007** | -3.774 | (14.772) | 62.289*** | (21.441) | -1.462 | (14.342) |
| Total rain-fed area owned | -.200e-7 | .172 | (1.473) | -2.906 | (44.819) | .145 | (1.246) |
| Distance to nearest town in 2005 | -.0002 | -.273 | (.540) | -1.245 | (.883) | -.372 | (.582) |
| Received credit in the past 2 years (yes = 1) | .010** | 25.690* | (14.953) | 77.500*** | (20.622) | 27.869** | (12.057) |
| Distance to nearest all-weather road in 2005 | .00002 | .003 | (.006) | .046 | (.052) | .007 | (.017) |
| Cooperative membership (yes = 1) | .002 | -39.462** | (17.711) | 4.252 | (22.139) | -37.516** | (13.734) |
| Other farmers association (yes = 1) | .001 | -11.135 | (17.913) | -12.273 | (24.085) | -11.487 | (15.863) |
| Have access to irrigation facility (yes = 1) | .044*** | 2.123 | (8.416) | 96.825*** | (32.743) | 7.501 | (14.700) |
| Have access to borehole (yes = 1) | -.001 | -27.997** | (12.694) | 4.065 | (20.639) | -29.473** | (12.106) |
| Have access to concrete well (yes = 1) | .003 | 10.086 | (16.951) | 3.890 | (25.137) | 10.049 | (13.792) |
| Area planed for pepper in 2005 (1000 ha) | .411e-4 | .660 | (2.347) | 2.751* | (1.541) | .628 | (1.997) |
| Area planed for rice in 2005 (1000ha) | -.279e-4 | -.475 | (2.359) | -2.584 | (1.672) | -.386 | (2.083) |
| Area planed for sugarcane in 2005 (1000ha) | -.158e-4 | -.597 | (.818) | -.027 | (3.226) | -.674 | (1.565) |
| Area planed for tomato in 2005 (ha) | .244e-4* | 2.212 | (2.802) | 1.340 | (.883) | 2.237 | (4.116) |
| Fadama II member * Rainfall (1000mm) | -.026*** | .247*** | (.086) | -.095 | (.061) | .239*** | (.044) |
| Fadama II neighbor * Rainfall (1000mm) | -.009 | -.016 | (.113) | -.050 | (.076) | -.020 | (.054) |
| Fadama II member * Rainfall CV | -.081 | .059 | (.437) | -.431 | (.496) | .058 | (.443) |

| | Selection | WTI (1000 Naira) | | | | | |
|---|---|---|---|---|---|---|---|
| | Marginal effect | OLS | | Tobit | | Heckman | |
| | | Coefficient | Std.err | Coefficient | Std.err | Coefficient | Std.err |
| Fadama II neighbor * Rainfall CV | -.116 | -.174 | (.569) | -.695 | (.632) | -.247 | (.498) |
| Fadama II member (yes = 1) | .498*** | -.234 | (.145) | .424*** | (.158) | -.208 | (.130) |
| Fadama II neighbor (yes = 1) | .083 | .041 | (.206) | .209 | (.192) | .061 | (.145) |
| Receive other financial aid for irrigation pump | .139*** | | | | | | |
| Intercept | | 65.491 | (52.428) | -332.583*** | (75.768) | 36.502 | (67.970) |
| Inverse Mills ratio | | | | | | 11.364 | (14.479) |
| $\sigma_2$ | | | | | | 46.868 | |
| $\rho$ | | | | | | .243 | |
| mean of squared residuals | | 52.920 | | | | 48.178 | |
| No of observations | 2232 | 160 | | 2232 | | 160 | |
| Log-likelihood | -328.00 | | | -2357.61 | | | |
| $R^2$ | | .857 | | | | | |
| *p*-value (overall fit) | | .000 | | .000 | | .000 | |

*Notes:* *, ** and *** denote variables significant at 10%, 5% and 1% respectively.
The estimates on state dummies are excluded from the table. All coefficients for Fadama II membership and interaction terms were rescaled to1/1000 to fit in the table.

## Table 6: Results from unobserved stochastic threshold (UST) model

| | WTI (1000 Naira) | | Threshold | |
|---|---|---|---|---|
| | Coefficients | 95% CI | Coefficients | 95% CI |
| Total value of irrigation pump in 2005 | .374 | [ -.24, .87] | | |
| Age | -1.017** | [ -2.21, -.41] | 1.707 | [ -.9, 141.2] |
| Household size | -.333 | [ -3.24, .95] | -3.518 | [ -343.7, 4.9] |
| Gender of respondent (female = 1) | .887 | [ -19.58, 37.95] | 309.151** | [ 33.6, 11400] |
| Education of respondent (years) | .204 | [ -2.85, 1.33] | 4.927 | [ -.9, 120.7] |
| Dependency | 2.382 | [ -1.38, 10.08] | 21.079** | [ .2, 404.7] |
| Total expenditure of 2005 (Naira) | .106 | [ -.04, .36] | .701 | [ -.2, 12.6] |
| Total value of asset (Naira) | .008 | [ -.01, .02] | .009 | [ -.01, .05] |
| Land ownership (own = 1) | -1.383 | [ -35.5, 30.1] | -118.421** | [ -6041, 0] |
| Total rain-fed area owned | .146 | [ -1.77, 2.91] | .149 | [ -7.6, 3.1] |
| Distance to nearest town in 2005 | -.374 | [ -2.42, 1.43] | 3.117** | [ 0.0, 121.7] |
| Received credit in the past 2 years (yes = 1) | 27.966** | [ 4.34, 80.48] | -92.208 | [ -3875, 13] |
| Distance to nearest all-weather road in 2005 | .007 | [ -.10, .01] | -.241 | [ -54.1, .4] |
| Cooperative membership (yes = 1) | -37.426** | [ -80.4, -10.5] | -60.354 | [ -1141, 136] |
| Other farmers association (yes = 1) | -11.406 | [ -67.1, 19.7] | -30.857 | [ -1873, 541] |
| Have access to irrigation facility (yes = 1) | 7.722 | [ -12.1, 56.5] | -284.980** | [ -9509, -31] |
| Have access to borehole (yes = 1) | -29.530** | [ -67.75, -6.69] | -7.554 | [ -486, 361] |
| Have access to concrete well (yes = 1) | 10.019 | [ -19.7, 41.6] | -31.895 | [ -932, 136] |
| Area planed for pepper in 2005 (1000 ha) | .610 | [ -7.35, 10.34] | -.006 | [ -.4, .1] |
| Area planed for rice in 2005 (1000ha) | -.377 | [ -10.1, 10.9] | .004 | [ -.03, .4] |
| Area planed for sugarcane in 2005 (1000ha) | -.671 | [ -9.18, 2.57] | .002 | [ -.04, .2] |
| Area planed for tomato in 2005 (ha) | 2.240 | [ -4.2, 11.02] | -1.635 | [ -175, 274] |
| Fadama II member * Rainfall (1000mm) | .238 | [ -.001, 6.53] | .653** | [ .1, 1.6] |
| Fadama II neighbor * Rainfall (1000mm) | -.021 | [ -.511, 4.21] | .127 | [ -.7, 7.5] |
| Fadama II member * Rainfall CV | .057 | [ -5.64, 48.9] | 1.338 | [ -2.0, 3.4] |
| Fadama II neighbor * Rainfall CV | -.247 | [ -13.1, 12.2] | 1.592 | [ -3.3, 6.5] |
| Fadama II member (yes = 1) | -.208 | [ -20.3, .254] | -1.615** | [ -5.6, -.8] |
| Fadama II neighbor (yes = 1) | .062 | [ -10.7, 3.9] | -.525 | [ -2.6, 2.9] |
| Receive other financial aid for irrigation pump | | | -517.767 | [ -12200, 125] |

| | WTI (1000 Naira) | | Threshold | |
|---|---|---|---|---|
| | Coefficients | 95% CI | Coefficients | 95% CI |
| Intercept | 35.717 | [ -3251, 1064] | 898.225** | [ 60, 20200] |
| Inverse Mills ratio | 11.684 | [ -23.4, 71.1] | | |
| $\sigma_1$ | 44.485 | | | |
| $\sigma_2$ | 394.592 | | | |
| $\rho$ | .366 | | | |
| mean of squared residuals | 45.931 | | | |
| No of observations | 160 | | 160 | |

*Notes:* ** denotes variables significant at 5%.
All coefficients for Fadama II membership and interaction terms were rescaled to1/1000 to fit in the table. For the confidence interval, a bias-corrected percentile is used since it has better small sample properties than approximated asymptotic confidence intervals (Efron, 1987).

## Table 7: Quantitative impacts of key household characteristics on threshold levels

| Household characteristics | Minimum investment level required to offset transaction costs |
|---|---|
| Female farmer | + $2434 |
| Household that owns land | - $932 |
| Distance to nearest town | + $25 |
| Have access to public irrigation facility | -$2461 |
| Fadama II member | - $1271 |
| Fadama II member * rainfall (1000mm) | + $514 |

*6.1 Results on thresholds*

The results from the UST model indicate that the minimum required investment level (threshold) is higher for the variables female farmers, higher dependency ratio, higher income, no land ownership, more distant from nearest town, and no access to irrigation facility. Being a Fadama II member in a more arid region also lowers the threshold.

The finding is in line with the literature showing that women are as willing as men to invest in an irrigation pump to improve slack season food production (Ogunjimi & Adekalu, 2002) and to start a micro-enterprise (Westby et al., 2005). In contrast, particularly in northern Nigeria, irrigation is still predominantly a male affair (Salisu, 2001) and this tradition may raise the transaction costs for women who wish to buy a pump.

A higher dependency ratio reduces the time available for working age household members to invest in a pump. The farther the nearest town is, the higher the threshold in the UST model. The distance to the nearest town, however, does not affect WTI in the UST model. Owning land can reduce the transaction costs of pump investment as land and pump are often complementary inputs and lack of ownership of land adds to the transaction costs of obtaining land and therefore the transaction costs for irrigation investment. Similarly, access to facilities for irrigation seems to significantly lower the transaction costs in the UST model, as farmers in this case are probably familiar with the qualities and functions of pumps used by others.

Being a Fadama II member seems to lower the transaction costs in areas with lower annual rainfall, either because membership enables farmers to benefit from various networks formed through the Fadama II projects, or because buying pumps as a group can lower the transaction costs for the individual, who does not need to search for sellers. The impact of Fadama II on WTI, on the other hand, seems insignificant in the UST model. These findings imply that while Fadama II may not affect farmers' WTI, it leads to higher total investment through the reduction in transaction costs. It is also noted that membership of Fadama II in areas with higher rainfall may lead to higher transaction costs, as farmers here are slightly better off and the opportunity costs of participating in Fadama II activities may be higher.

As expected, qualitative differences between the results from the Heckman and the UST models are relatively small. The results from the UST model, however, still add improvements to the Heckman model in the form of 1) predictability of WTI and 2) quantitative information on the impacts of unobserved transaction costs. For the predictability of WTI, we compare the sample mean of squared residuals from structural equations following Cogan (1981). As in Tables 5 and 6, the UST model leads to smaller mean of squared residuals (45.931) than are obtained with the Heckman model (48.178), indicating the better predicting power of the former.

To interpret the quantitative meaning of the coefficients in the threshold equation, Table 7 compares the effects of key factors on thresholds with the median level of current investment for irrigation pumps. The threshold investment level is raised by $2434 for being a female farmer, $160 with 1 unit increase of household dependency ratio (= $40 with one more child in a household with four working age members and five dependent members), $25 with 1 km increase in distance to the nearest town, but reduced by $932 for owning land, $2461 for having access to irrigation facilities and $2468 for being a Fadama II member in the LGA with 1500 mm of annual rainfall and its coefficient of variation of 0.2. Although these are only estimates, their sizes compared to the median investment level indicate that the effort to reduce the transaction costs may lead to a significant increase in farmers' investment in irrigation, even without affecting the returns to such irrigation investments.

The quantitative information in Table 7 is only indicative, and more information is needed to assess how this information can be used to help design policies aimed at increasing investment in irrigation pumps by lowering the transaction costs. Nevertheless, the results show clearly that transaction costs significantly affect farmers' decision making with respect to investment in these pumps.

*6.2 Results on willingness to invest (WTI)*

The results in the UST model indicate that WTI is higher for a household with a younger household head, experience of receiving credit in 2005, non-membership of a cooperative, and no access to a borehole. While the Tobit model suggests that WTI is affected by the total value of irrigation pumps in 2005, other variables – the gender of the household head, land ownership, access to irrigation facilities, area planted for pepper in 2005, and Fadama II membership in a more arid region – are not found significant in the UST model, indicating that using the Tobit model may significantly distort the factors affecting WTI. Similarly, while the Heckman model suggests a significant effect for the total value of irrigation pumps in 2005 and access to a borehole, the interactive terms of Fadama II membership and rainfall characteristics are not significant in the UST model. Given the better predictability of the UST model over the Heckman model, the results indicate that the Heckman model may be less appropriate than the UST model for estimating willingness to invest in an irrigation pump.

Although the findings on age are counterintuitive, as older farmers often prefer labor-saving devices, a possible reason is that they be used to using simpler devices like the shadoof and reluctant to try more sophisticated devices. Moreover, they tend to be risk adverse. Farmers' receipt of credit in 2005 is a good indicator for their access to similar credit in 2006 and thus the results indicate that farmers are still facing liquidity constraints and their WTI can be raised by giving them more access to credit. No access to a borehole increases WTI, as a borehole can substitute for a pump. Not belonging to a cooperative may also increase WTI, since non-members cannot take advantage of group ownership of pumps or hire from other members. Besides, non-members may be fairly well-to-do and thus not need the support of the cooperative.

Overall, the results reveal many important aspects of farmers' investment in irrigation pumps. Of these, the effects of gender of household head, distance to nearest town and Fadama II membership are particularly interesting. Women face a bigger challenge than men when trying to buy a pump, but once they do they can realize as high a return from investment as their male counterparts. Farmers who live a long way from the market also face a bigger challenge than those who live close by, but once they succeed in investing in a pump they can realize as high a return. Lastly, a community-driven development program like Fadama II benefits farmers mostly by decreasing the transaction costs of investment, rather than by increasing the returns to investment.

## 7. Conclusions

African farmers' investments in productive assets are affected both by the returns to such investment and the transaction costs associated with making such investments. While a fair amount of research has been done on the factors affecting returns to irrigation technology, less is known about how big an effect transaction costs have on farmers' decisions to invest, and what factors increase or reduce such effects, partly because transaction costs are often unobserved or only partially observable. High transaction costs in sub-Saharan Africa, however, are considered significant limiting factors for farmers' adoption of modern production technologies and it is imperative to identify the extent to which these costs discourage farmers' from investing in these technologies.

This article applies the unobserved stochastic threshold (UST) model to assess the magnitude of the impact of transaction costs on farmers' investment in irrigation pumps in Nigeria. The findings suggest that the impacts of these costs are associated with various socio-economic characteristics of farmers, some of which do not affect the farmers' willingness to invest. The findings also indicate that the threshold can be significantly lowered for farmers who are aware of the potential benefits of irrigation pumps but are discouraged from investing in a pump because of the high transaction costs involved. This can be achieved by offering more support to female farmers, constructing roads to link farmers to the nearest town, and providing more support to community-driven development projects such as Fadama II, especially in the dry savanna region.

In terms of methodology, this article provides an empirical example which shows that, although the main benefit of the UST model lies in its ability to provide more quantitative information associated with transaction costs, the farmers' willingness to invest in irrigation pump can also be better predicted by this model than by the Heckman or Tobit models. Although more studies are needed to assess the generality of such benefits of the UST model, this article suggests that it could be very informative in assessing the effect of transaction costs in irrigation pump investment in other sub-Saharan African countries, particularly when there is a good reason to believe that such costs and therefore thresholds vary significantly across individual farmers.

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