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Measuring the Effect of Transaction Costs for Investment in Irrigation Pumps: Application of Unobserved Stochastic Threshold Model to the Case of Nigeria

Hiroyuki Takeshima

Development Strategy and Governance, IFPRI, Nigeria

Adetola I. Adeoti

Department of Agricultural Economics, University of Ibadan, Nigeria

Sheu Salau

Development Strategy and Governance, IFPRI, Nigeria

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International Food Policy Research Institute
c/o International Center for Soil Fertility and Agriculture
Development
No.6/ Plot 1413 Ogbagi Street
Off Oro-Ago Crescent
Cadastral Zone 11, Garki, Abuja
Nigeria
E-mail: ifpri-nigeria@cgiar.org
www.ifpri.org

IFPRI HEADQUARTERS

International Food Policy Research Institute
2033 K Street NW
Washington, DC 20006-1002 USA
Tel. +1-202-862-5600
Fax +1-202-467-4439
E-mail ifpri@cgiar.org
www.ifpri.org

THE NIGERIA STRATEGY SUPPORT PROGRAM (NSSP)

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- Enhanced knowledge, information, data, and tools for the analysis, design, and implementation of pro-poor, gender-sensitive, and environmentally sustainable agricultural and rural development policies and strategies in Nigeria;
- Strengthened capacity for government agencies, research institutions, and other stakeholders to carry out and use applied research that directly informs agricultural and rural policies and strategies; and
- Improved communication linkages and consultations between policymakers, policy analysts, and policy beneficiaries on agricultural and rural development policy issues.

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Adetola I. Adeoti

Department of Agricultural Economics, University of Ibadan, Nigeria

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Table of Contents

Introduction	1
Transaction Costs Associated with Irrigation Pump Investment in the Nigerian Context	2
Estimation of Threshold Determined by Transactions Costs	3
Conceptual Framework.....	3
Demand Factor and Adoption Decision of Small-scale Irrigation Technologies by Farmers	3
Methodology and Data	5
UST, Heckman, and Tobit Estimation Methods	5
Selections of Variables from Fadama II Dataset and Rainfall Data.....	7
Empirical Results	10
Minimum Required Investment Level under Transaction Costs (Thresholds)	10
Willingness to Invest (WTI)	13
Conclusion	14
References	16
Appendix 1: Lifetime Indirect Utility Function in Rosenzweig and Wolpin (1993) and its Modification	18

List of Tables

Table 1. Statistics from Historical Rainfall Data in Various Locations ^{ab}	8
Table 2. General Household Characteristics	9
Table 3. Investment in Irrigation Pumps in 2006 by Fadama Membership	9
Table 4. Investments in Irrigation Pumps in US \$.....	9
Table 5. Results from Conventional Models (results of state dummies are omitted)ab.....	12
Table 6. Results from the Unobserved Stochastic Censoring Threshold Modelab	13
Table 7. Quantitative Impacts of Key Household Characteristics on Threshold Levels.....	13

List of Figure

Figure 1. WTI, Unobserved Threshold and Observed Investment Level.....	5
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Abstract:

Small-scale private irrigation schemes (SPRI) have been the driving force behind the expansion of irrigated areas in Nigeria, despite government efforts to promote large-scale public irrigation schemes. SPRI allows adjustment of irrigation schedules in accordance with observed crop needs. The irrigated area in Nigeria is, however, far below its potential and an increase in farmers' investment in irrigation is essential. While Nigerian farmers' low level of investment in irrigation may be partly due to low returns, it is also the result of high transaction costs associated specifically with making such an investment. Although reducing transaction costs is important because the reduction provides farmers with a more enabling environment, transaction costs are often unobservable and little is known about what factors contribute to them. This article empirically assesses the effect of unobserved transaction costs for Nigerian farmers' when investing in irrigation pumps, using the baseline survey data for the Second Fadama Development Program (Fadama II). The results indicate that the unobserved transaction costs are higher for female landless farmers, with higher dependency ratio and residing far from town. The results suggest that the unobserved transaction costs can be as important as the factors determining the profitability of irrigation pump, emphasizing the importance of reducing transaction costs in addition to improving the environment for higher return from irrigation investment.

Executive Summary

Small scale private irrigation schemes (SPRI) have been popular among Nigerian farmers who have enough resources to invest in them. The adoption of the irrigation pump is a key factor responsible for the expansion of irrigated land in Nigeria in recent years. The pumps are commonly adopted because they allow one hectare of land to be irrigated at a time while traditional water-lifting devices such as shadoufs can irrigate only up to 0.1 hectare at a time. These pumps also fill in the labor gap associated with the aging of farmers, which is becoming a serious issue in Nigeria, compounded by the rapid out-migration from rural communities. The demand should therefore be high for labor-saving devices such as irrigation pumps. However, the pace of adopting irrigation pumps in Nigeria is low relative to their potential. While the actual investment in irrigation pumps is determined by factors that affect the return per investment, the transaction costs could be considered as one of the important limiting factors. In particular, these costs, from a farmer's point of view, are the identification of sellers, making certain of the pump's quality, and the time and transportation costs for purchasing it. Farmers often need whole packages of complementary inputs (farm land, water, improved seeds, fertilizer, fuel, and electricity) for using an irrigation pump, but may incur high transaction costs for obtaining those inputs. Farmers often make repeated trips to pump suppliers as pumps are not always in stock and farmers only learn of their availability by actually travelling to the shop, further raising the transaction costs. In Africa, such transaction costs are generally high and often discourage farmers from making investments that are profitable and could lead to productivity growth. In addition, these transaction costs are often specific to individual farmers and unobservable. Government policies to lower these transaction costs would be essential for increasing farmers' investment in irrigation pumps.

While various studies have examined factors affecting returns of irrigation technology, less is known about the impacts of the aforementioned transaction costs on farmers' decisions. Analyzing this impact can provide critical information about how to promote private adoption of the irrigation pump in Nigerian agriculture. This study estimates how transaction costs relate to the socioeconomic characteristics of farmers and to what extent they lead to non-investment in irrigation pumps. This study focuses on the irrigation pump investment under the Second Fadama Development Program (Fadama II). Locations benefiting from Fadama II are selected for study because there is rich information about various socioeconomic characteristics contained in the dataset that evaluated this program. Importantly, these transaction costs are often independent of the level of investment farmers plan to make, such as the price of pump itself, and thus only farmers who plan to make large investment will actually do so in the presence of high transaction costs.

The main findings of the study indicate that female-headed households face higher transaction costs and find it worthwhile to incur such costs only when they are willing to invest US\$2,434 more in pumps than male-headed households of the same characteristics. Female-headed households, however, can realize the same high returns per investment as male-headed households when they actually invest. Farmers located far from the nearest market are less likely to invest in irrigation pump due to the higher transaction costs (the minimum investment level for pump needed to justify incurring transaction costs rises by US\$25 for every 1 kilometer added to the distance between the farmer's residence and the nearest market). The minimum investment level required is also higher for households that do not own their land, do not have access to public irrigation facilities, and have a high ratio of nonworking household members to working-age household members.

Being a member of the Fadama II project seems to significantly lower the transaction costs of investment, particularly in the dry regions, although Fadama II membership does not affect how much farmers are willing to invest. The impact of the Fadama II project is unique and slightly different from the provision of subsidy alone, because subsidy for an irrigation

pump, which is part of the Fadama II project, is expected to affect the farmers' actual investment level and not the transaction costs of investment. The Fadama II project members therefore seem to benefit from other factors derived from the project. Such benefit includes (a) the capacity building of farmers' networks, which lowers the cost for individual farmers to search and locate irrigation pump suppliers and to learn about the quality of the pump being supplied, and (b) infrastructure such as improvement and extension of roads that lowers the farmers' costs of traveling to the pump market.

In conclusion, transaction costs associated with investment in irrigation pumps, though not fully observable, seem substantially high in Nigeria. It is also known that investment in irrigation pumps may be limited by the lack of a profitable environment with a low output price and the lack of complementary inputs such as fertilizer or improved seeds. This study suggests that the investment is further limited by high transaction costs associated specifically with making such an investment. Many household characteristics also affect the transaction costs for investing in irrigation pump, while they may not affect the profitability of investment once made. Non-investment in irrigation pump is therefore not necessarily due to the lower expected profitability from the investment, but may be due to the transaction costs associated with making such investment. The findings re-emphasize the importance of reducing market failure and creating an enabling environment in which farmers can engage in profitable farming activities. Support to female-headed households, the facilitation of land trade or rental, strict enforcement of land ownership title and rural infrastructure would be especially helpful. Such measures alone may significantly increase farmers' purchase of irrigation pumps. They may even do so in the absence of policies or the environment that raises the return on the irrigation pump, such as a subsidy for buying irrigation pumps or other agricultural inputs.

Introduction

Small-scale private irrigation schemes (SPRI) are reported to be more successful in Nigeria than publicly-run large-scale irrigation schemes. SPRI are popular among Nigerian farmers particularly because they allow irrigation schedules to be adjusted according to observed crop needs (Dauda et al. 2009). Among the many types of private irrigation equipment, modern water-lifting devices are essential for expanding the planted area, raising yield for certain crops, and allowing some farmers to undertake dry-season production of food and cash crops.

For lifting water, Nigerian farmers commonly use a shadouf, treadle pump, or motorized pump. Although the performances of these tools vary, typically a motorized pump has the capacity to irrigate 1 hectare (ha) of land while a treadle pump and a shadouf could irrigate 0.2–0.5 ha and less than 0.1 ha of land, respectively (Omilola 2007). The use of a shadouf is very laborious, time-consuming, and relatively inefficient due to the low discharge and flow rates. The relative success of private irrigation schemes in Nigeria indicate that farmers can significantly benefit from investing in various types of irrigation equipment, including pumps.

Only a few of farmers, however, currently own pumps, as indicated by the dataset collected for the impact assessment study of the Second National Fadama Development Project (Fadama II)¹, which was used in Nkonya et al. (2008). However, the adoption of engine-driven irrigation pumps is becoming common in certain parts of Nigeria (Pasquini et al. 2004). In the Fadama II dataset, only about 12 percent of respondents individually own irrigation pumps and 5 percent own pumps as a group. However, these two categories of pump owner live in places where both surface water and underground sources of water are relatively accessible.

There are three main reasons why the observed investment level is low for irrigation pumps: the profitability of investment, financial constraint and transaction costs. First, the demand for irrigation pumps should of necessity lead to improved profitability. Second, farmers may not prefer purchasing an expensive pump, unless they have access to finance. Finally, a reliable source of water; inexpensive and stable supply of fuel, capacity for maintaining the pumps all affect the willingness to invest (WTI) in the pumps which is influenced by transaction costs². Even though the WTI may be high, the high transaction costs associated with such investments may discourage farmers. Transaction costs are the costs for organizing economic systems (Arrow 1969), or in this particular case, cost of obtaining an irrigation pump, which is different from the price of the pump itself. These are the costs of searching for pump sellers, finding information on the quality of particular types of pumps, and taking the time and paying the transportation costs associated with buying a pump. The transaction costs generally drop as the market for irrigation pump becomes more liberalized, which has led to the growth of pump usage and expansion of irrigated area in many Asian countries such as Bangladesh (Hossain 2009). Thus, the relatively liberalized pump market in Nigeria also provides some promise. Transaction costs, however, tend to remain high in many African countries due to the market failure, and government policy reforms could help to reduce such costs. Reducing transaction costs has, however, been a challenge as they are farmer-specific, observable only to each farmer, and cannot always be measured in monetary terms.

The focus of this study is on transaction costs associated with investment in irrigation pumps. It attempts to relate unobservable transaction costs to observable farmer characteristics. It assumes that transaction costs are linked to a particular threshold level, or

¹ approach that emphasizes social cohesion or more inclusiveness in the management of community resources and governance. Pilot asset acquisition is one of the key components of Fadama II and it covers the assistance for the purchase of moderately-priced irrigation pumps and other equipment required to enhance productivity growth and value addition activities.

² More explicitly, WTI in this paper is defined by equation (8) in the conceptual framework.

minimum WTI for a farmer to justify incurring the fixed transaction costs to invest in an irrigation pump. Although the thresholds are unobservable, they are assumed farmer-specific, and comparable to WTI. First, we empirically examine whether some of the observable household characteristics affect or do not affect the thresholds, and by how much if they do. We apply the unobserved stochastic censoring threshold (UST) model by Nelson (1977) and Cogan (1981) to the Fadama II dataset. Second, we assess how the UST model improves on other simpler and popular but more restrictive models—such as Tobit by Tobin (1958) and Heckman's (1979) model—which incorporate the unobserved farmer-specific thresholds. This study contributes to the literature in two ways. First, it provides an empirical example of how high transaction costs in Sub-Saharan Africa (SSA) affect farmers' investment decisions about irrigation equipment. It identifies factors that affect such transaction costs and, within certain assumptions, the magnitude of such impacts. Although other studies have discussed the issue of transaction costs associated with investment, they have yet to provide empirical estimates to substantiate their conclusions. Second, this study employs a methodology widely used in the labor economic literature but less commonly used in agricultural economics literature—in spite of its potential to provide reliable estimates of the effects of transaction costs on farmers' investment in irrigation pumps.

Transaction Costs Associated with Irrigation Pump Investment in the Nigerian Context

Empirically studied transaction costs for SSA farmers typically include the costs of obtaining information, liquidity constraints, and the lack of or failure to enforce laws or regulations that protect the rights of farmers (Key, Sadoulet, and de Janvry 2000). The transaction costs associated with investments in irrigation pumps are similar, and conditions observed in Nigeria point towards the existence of these costs.

A pump has higher resale value than a well or tubing (Rosenzweig and Wolpin 1993). There are thus more personal investments in pumps than in the wells or tubing that are often purchased in group. The transaction costs associated with the purchase of a pump may thus be individual-specific. Transaction costs for irrigation pump investment in Nigeria are often represented as travel time, transportation costs, search costs for a desired model or quality, and the cost of obtaining information about the operation of the pump.

Farmers have to spend time in search of service providers unless they are introduced to such providers. Service providers and pump sellers generally congregate in cities such as Kano and Abuja. Farmers seeking irrigation pumps must therefore travel far to increase their options and get the right model and price. The travel time to the cities depend on how good the roads are and the frequency of transport. Depending on the distance of the farm from the sellers, the state of the road, and the type of transport (motor bike, bus or car), transportation costs could be quite substantial and are compounded if there is need for repeated visits. Multiple visits often arise when the trusted seller is out of stock, when the model is not available, or when the farmer is not satisfied with the performance of the pump.

Farmers may also spend time searching in the open market for a preferable model. Even when they are introduced to sellers, farmers want to verify that they are receiving a competitive price. The farmer also has one more burden—they must check the pumps quality as pump adulteration is likely because the quality control system for pumps is still weak in Nigeria.

The cost of learning to operate a pump may be less substantial in Nigeria as extension workers, Fadama office facilitators, international NGOs, pump sellers, and other farmers are available to help them learn how. However, female farmers may face a different situation due the scarcity of female extension agents and culture. Research has shown that the scarcity of female extension agents has often been a limiting factor and therefore, female

farmers' adoption of new agricultural production technologies in Nigeria may be less (Laha, Goldey and Jones 2000). For example, Hausa female farmers may find it difficult to communicate with their male counterparts, Searching for a female extension agent could lead to higher transaction costs for them. Furthermore, in Nigeria, the Hausa culture dictates that the men predominately manage the irrigation systems (Abubakar 2002), potentially raising the transaction costs for women to invest in the irrigation pump.

Estimation of Threshold Determined by Transactions Costs

Although there are a number of investment studies that consider high fixed transaction costs, these studies either focus on observable costs or qualitative and not quantitative aspects of such costs. Several studies have modeled the demand determinants for durable production assets in the presence of certain types of market failures (Rosenzweig and Wolpin 1993). With respect to the agricultural sector, the Heckman's (1979) model and its variants have been widely applied to explain how high transactions costs affect subsistence farmers' decisions to participate in the market (Goetz 1992; Heltberg and Tarp 2002). Only a few studies have assessed the actual size of transaction costs or their threshold level in regards to people's decisions about investment or market participation (Renkow, Hallstrom, and Karanja 2004), and these focused on transaction costs assumed observable (Mburu, Karanja-Lumumba, and Mwai 2008). Moreover, the model employed by Renkow et al. (2004) requires a rather more intensive computation than the one needed for this study.

One of the most popular models to assess the size of transaction costs and the threshold level is the unobserved stochastic threshold (UST) model by Nelson (1977), Cogan (1981) and Maddala (1983), which has long been applied to analyze workers' labor market participation decisions and to estimate these threshold levels. The application of the UST model in the agricultural sector is relatively scarce except Key et al (2000) which used an extended UST model to analyze farmers' market participation decisions in Kenya.

Conceptual Framework

Demand Factor and Adoption Decision of Small-scale Irrigation Technologies by Farmers

This study modifies the Key, Sadoulet, and de Janvry (2000) and Bellemare and Barrett (2006) utility maximization problem, which together provide a good framework for understanding how transaction costs constrain Nigerian farmers' economic activities. Their models are modified to explicitly incorporate the investment in pump and transactions costs associated with it. It is postulated that an agricultural household faces the modified utility maximization problem in Equation 1 in which the household's utility at time t (ut) is a function of consumption of k-goods (ck) and other factors zu. The utility is a sum of future utility discounted with factor δ. It is the discrete variable which equals 1 if a farmer invests or divests in irrigation equipment at period t and 0 otherwise.

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

subject to

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

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

$$W_{t+1} = W_t - \sum_l \tau_t(z_\tau) \cdot I_t \quad (4)$$

$$G(q, x, S_t; z_q) = 0 \quad (5)$$

$$c_{kt}, q_{kt}, x_{kt}, s_t \geq 0 \quad (6)$$

Equation (2) states the cash or budget constraint, in which the sum of net revenue from market trading of goods k [which equals price of goods k at t (p_{kt}) times net sales quantity (m_{kt})] plus external income received at t (T_t) plus unproductive liquid asset at the beginning of period t (W_t) not be less than the amount invested for 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 quantity used as inputs (x_{kt}).

Equation (4) states that at the beginning of t , a farmer must have enough liquid assets to cover the fixed transactions costs (τ_t (z_t)) which are assumed to be a function of factors z_t associated with irrigation pump investment if they invest.

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 .

Equation (6) states that the quantity of goods k consumed, produced, used as inputs at time t , as well as investment in irrigation pump at t should be greater than or equal to zero.

In order to solve the utility maximization problem (1) through (6), this study follows one of the seminal papers by Rosenzweig and Wolpin (1993), which presents a similar model for farmers' pump investment in India. Then, our study applies Bellman's equation (Bellman 1952)³ to the expected lifetime utility function. Rosenzweig and Wolpin's (1993) specification is summarized in Appendix 2.

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

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

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 . 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 a farmer incurs fixed transaction costs $\tau = \tau'$ in investing. As τ is independent of the level of s^* , only farmers with significantly high s^* incur τ' and actually invest s^* because τ is small relative to the size of benefit realized from high s^* . Similarly, farmers with lower s^* are less likely to incur τ' , and therefore, less likely to invest s^* . A key interest in this study is how a policy can reduce τ so that more farmers decide to incur τ and invest s . As has been discussed, how τ can be reduced can be assessed by identifying the factors affecting threshold level.

³ Bellman's equation essentially states that the dynamic optimization problems can often be reduced to the optimization at the first period.

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

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

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

We assume that a farmer invest in irrigation 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

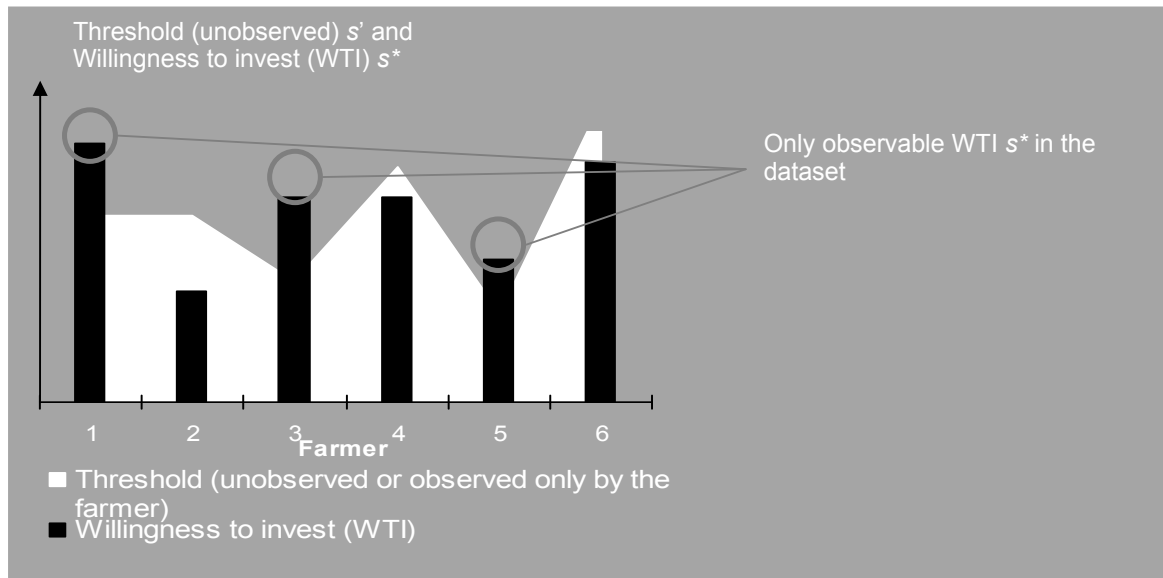
$$V_Y|_{s=s'} = V(z_q, p_k, S, s, \tau, \varepsilon | s=s^*, \tau = \tau') = V(z_q, p_k, S, s, \tau, \varepsilon | s=0, \tau = 0) \quad (11)$$

Then a farmers' decisionmaking mechanism on whether to invest in an irrigation pump can be simplified into the comparison between s^* and s' , such that,

$$\begin{array}{ll} \text{invest } s^* & \text{if } s' \leq s^* \\ \text{does not invest} & \text{if } s' > s^* \end{array} \quad (12)$$

The empirical analysis in the next section will be based on the assumption (Equation 12) in which s^* is observed only for those who actually invest, and s' is unobserved for all farmers, which is illustrated in Figure 1.

Figure 1. WTI, Unobserved Threshold and Observed Investment Level



Source: Authors.

Methodology and Data

UST, Heckman, and Tobit Estimation Methods

Following Cogan (1981), Nelson (1977) and Maddala (1983), we assume both the optimal level s^* and threshold s' are linear functions of observed characteristics;

$$s^* = \alpha_1 + \beta_1 \cdot X_i + \gamma_1 \cdot Z_{i1} + \varepsilon_{i1} \quad (13)$$

$$s' = \alpha_2 + \beta_2 \cdot X_i + \gamma_2 \cdot Z_{i2} + \varepsilon_{i2} \quad (14)$$

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

in which ε_{i1} and ε_{i2} follow the joint normal distribution with correlation ρ . 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') 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

$$\begin{aligned} s_i &= s^* \text{ if } s^* > s' \\ s_i &= 0 \text{ otherwise} \end{aligned} \quad (16)$$

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

Although this study focuses on the estimation of threshold, it is also beneficial to see how the estimation of WTI is improved in using the UST method compared to other alternative estimation methods that employ more restrictive assumptions but are simpler and more widely used. Popular alternatives to UST are Tobit (Tobin 1958) and Heckman's (1979) sample selection models. Both Tobit and Heckman share common features with UST as they explore the unobserved thresholds and incorporate its effect into the estimation of WTI. The UST exploits more information from the dataset than Heckman and Tobit, while Tobit adds more restrictions to Heckman and Heckman adds more restrictions to UST as described below in (17) through (22). The UST, however, is usually unavailable in standard software packages including STATA (unlike Heckman and Tobit), and thus the way in which UST improves over Heckman and Tobit is informative.

Heckman follows similar structure to UST except that in Heckman, a new latent variable is defined s_H in the place of s' , which is denoted s_H here. In Heckman, we have

$$s^* = \alpha_1 + \beta_1 \cdot X_i + \gamma_1 \cdot z_{i1} + \varepsilon_{i1} \quad (17)$$

$$s_H = \alpha_H + \beta_H \cdot X_i + \gamma_H \cdot z_{iH} + \varepsilon_{iH} \quad (18)$$

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

and

$$\begin{aligned} s_i &= s^* \text{ if } s_H > 0 \\ s_i &= 0 \text{ otherwise} \end{aligned} \quad (20)$$

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

$$\begin{aligned} s_i &= s^* \text{ if } s' < s^* \\ s_i &= 0 \text{ otherwise} \end{aligned} \quad (16')$$

While the censoring rule in UST is $s' < s^*$, the rule in Heckman is $s_{iH} > 0$. Heckman is more restrictive than UST because it forces the censoring threshold at 0.

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

$$s^* = \alpha_1 + \beta_1 \cdot X_i + \gamma_1 \cdot z_{i1} + \varepsilon_{i1} \quad (21)$$

in which

$$\begin{aligned} s_i &= s^* \text{ if } s^* > 0 \\ s_i &= 0 \text{ otherwise} \end{aligned} \quad (22)$$

In other words, Tobit adds an additional restriction of $s^* = s_H$ to Heckman.

In the context of farmers' irrigation investment decisions, the additional restrictions added in Tobit and Heckman over 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, while the UST and Heckman model is free from that 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's model can well predict the qualitative results obtained in the UST model (for example, the sign and significance of estimated coefficients for a threshold in the UST model can be easily predicted from the same estimates of coefficients in the selection equation in the Heckman mode), but not quantitative results which would be informative in assessing the gap between farmers' WTI and their threshold.

Selections of Variables from Fadama II Dataset and Rainfall Data

In this study, we use two datasets: the Fadama II dataset and rainfall data. A detailed description of the data collection framework for the Fadama II dataset is provided in Nkonya et al. (2008). Rainfall data are obtained from the Nigerian Meteorological Agency for locations near each state.

The variables in X_i , which are expected to affect both the WTI and the threshold, include the following:

- General information about the respondent (age, gender, and years of education);
- Household characteristics (dependency ratio, household size, total household expenditure in 2005, total asset value in 2006, whether the household owns part of its 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 to fadama ii project (whether the farmer is a member of fadama ii, or a non-member in the local government area (lga) operating fadama ii (fadama ii member) or resident in the lga that is not participating in the fadama ii (fadama ii neighbor));
- Other membership (whether the farmers belong to cooperatives, or any other farmers' association)
- Access to water-management facilities (whether the farmer currently has access to any type of irrigation facility, borehole, or concrete well); and
- Planted area for commonly irrigated crops (area planted for pepper, rice, sugarcane and tomato in 2005) and dummy variables for state.

The X_i also include variables in which Fadama II membership is combined with the historical average of annual rainfall and a coefficient of variation for that annual rainfall, which is used as a measurement of the level of rainfall risks. The significantly higher difference is observed in the coefficient of variation among cities (Table 1), indicating the possibility of

heterogeneous WTIs across regions due to varying rainfall risks. Risk associated with irrigation technology creates more costs for farmers who are considering whether to buy irrigation pumps as it affects the amount of information farmers require about the appropriate operation of the devices. The average rainfall and rainfall risks are combined with Fadama II membership because Fadama II members (and to some extent Fadama II neighbors) face fewer liquidity constraints for irrigation pump investment and the effect of rainfall level and rainfall risks become more important factors for them in making a decision about whether to invest in irrigation technology (Koundouri, Nauges, and Tzouvelekas 2006; Phillip et al. 2009), while for other farmers, liquidity constraints are more dominant factors than the rainfall conditions. Including rainfall data as an interaction term also avoids perfect multicollinearity with state dummy variables (rainfall data are available only at the state level).

Table 1. Statistics from Historical Rainfall Data in Various Locations^{ab}

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

^a Source: Nigerian Meteorological Agency (2009 for all locations except Adamawa and Taraba, whose numbers are extracted from Oyekale (2009).

^b The average and coefficient of variation are from 1970s through 2006 depending on the locations and data availability.

The total value of an irrigation pump in 2005 is used for variable z_{i1} , although farmers who have already invested in irrigation pumps may have lower WTI in 2006 and thus the levels of their investment may not affect their thresholds. Including the total value of an irrigation pump in 2005 in z_{i1} is appropriate because the actual transaction costs arise more from transportation and the number of visits farmers need to make to negotiate the price, and thus, are independent of farmers' irrigation pump investment level in 2005. Similarly z_{i2} is captured by the availability of other financial assistance, which is indexed by whether the farmer received financial assistance other than Fadama II for an irrigation pump either before or after Fadama II implementation⁴. The availability of other financial assistance can lower the threshold, but does not affect the WTI.

After dropping the data with missing variables, we used a total of 2,232 observations in the analysis, out of which 160 households invested in irrigation pumps in 2006. Households in the dataset have typical characteristics of rural households in SSA— a low education level, low expenditure level, and location remote from infrastructure (Table 2). Most of the farmers who invested in irrigation pumps in 2006, however, are male, own at least part of the land they cultivate, and are members of the Fadama II project.

⁴ Although the existence of such financial assistance was only observed when farmers actually invested in pumps using the assistance, it is believed to be a fairly good indicator of the availability of such assistance. This leads to the assumption that this variable is not endogenous to farmers' investment decisions. It is because some of that assistance provides farmers with pumps for virtually free (such as the case of SPFS) and thus if the assistance is available farmers have no reason not to receive the pump. The type of pump is, however, limited and thus such assistance does not affect farmers' WTI. Moreover, the scale of operation by SPFS is smaller than Fadama II and thus the impact of Fadama II on farmers' investment on irrigation pump is still expected to be significant even in the presence of assistance other than Fadama II.

Table 2. General Household Characteristics

	All observation		Those who invested in irrigation pumps (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 (percent)	14	0.7	20	3
Fadama II member (percent)	36	1.0	88	3
Fadama II neighbor (percent)	36	1.0	8	2
Own land (percent)	65	1.0	81	3
Total area of land owned (ha)	1.2	40687	3	7
Total area of rain-fed land owned (ha)	1.0	40633	2	5
Have access to irrigation facility percent)	2	0.3	14	3
Have access to borehole (percent)	19	0.8	28	3
Have access to concrete well (percent)	13	0.7	14	3
Area planted for pepper (2005, ha)	39	9115	301	10750
Percent of those growing pepper	7	0.5	17	3
Area planted for rice (2005, ha)	2	5112	2	7391
Percent of those growing rice	25	0.9	40	4
Area planted for sugarcane (2005, ha)	2	2918	2	4556
Percent of those growing sugarcane	27	0.9	43	4
Area planted for tomato (2005, ha)	1	5	1	3
Percent of those growing tomato	30	0.9	49	4
Member of cooperative (percent)	20	0.8	19	3
Member of other farm organization (percent)	24		11	2
Value of irrigation pump in 2005 (US\$)	236	868	283	1033
Who had irrigation pump in 2005	7		24	3

^aThe median and standard deviations for area planted for four crops are for the producers of these crops.

^bUSD \$1 = 127 Naira

Among Fadama II members, approximately 14% (118 out of 804 farmers in the dataset) invested in irrigation pumps using financing from Fadama, while some other farmers invested in pumps using other finance sources (Table 3). Interestingly, while the proportion of male farmers who invested in irrigation pumps is slightly higher than that of female farmers, those female farmers who did invest in irrigation pump generally invested more than the male farmers (Table 4). This seems to indicate that while female farmers may have the same or even higher WTI than male farmers, they may face higher transaction costs so that only those with significantly high WTI invest in irrigation pump.

Table 3. Investment in Irrigation Pumps in 2006 by Fadama Membership

	Fadama financed	Other sources of finance	Total)
Fadama member	118 / 804	22 / 804	140 / 804
Non-Fadama member within Fadama LGA	0 / 796	12 / 796	12 / 796
Non-Fadama LGA	0 / 632	8 / 632	8 / 632

Table 4. Investments in Irrigation Pumps in US \$

	Observations	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

The dataset also indicates that irrigation pumps are most widely used to irrigate peppers, rice, sugarcane, and tomatoes. The areas planted for these four crops in 2005 can be good proxies for farmers' WTI in an irrigation pump, and may also affect their exposure to

irrigation technologies and thus the threshold level. As in Table 2, the proportion of farmers growing these crops was higher among those who invested in a pump in 2006 and the areas planted were usually more than 1 hectare.

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

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

Whether Fadama II members purchase irrigation pumps or not may also be affected by other members' interests⁵. It is possible that other farmers' transaction costs may affect certain farmers' decisions not to purchase pumps through Fadama II. This study, however, assumes that the UST model can fairly accurately represent the effect of transaction costs on farmers' decisions about irrigation pump investments. The development of a model that reflects such a complex decisionmaking structure is left for future study.

Empirical Results

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

Minimum Required Investment Level under Transaction Costs (Thresholds)

The results in the UST model indicate that the minimum required investment level (threshold) is higher for female farmers, farmers with a higher dependency ratio, higher income, no land ownership, who are more distant from the nearest town, and have no access to an irrigation facility. Being a Fadama II member in more arid regions, on the other hand, lowers the threshold.

⁵ In Fadama II, farmers may obtain the irrigation pump in the following way: Farmers can first decide to participate in the Fadama User Group (FUG) based only on their readiness to contribute their own funds which are required for various activities agreed upon by the members and carried out by the group. Such activities include the purchase of irrigation pumps at subsidized cost. Pumps can therefore be purchased using Fadama II funds if all members in the FUG agree unanimously. Once all members of the group agree to obtain irrigation pumps, the members buy the pumps as a group or individually with 70% subsidy, unless the total subsidy exceeds \$5000 for the entire group. In principle, each farmer in the group can obtain a different type of pump based on his or her needs. The process of acquiring pumps this way can be time-consuming and assumed to vary widely across a state or regions within states. Aside from pump acquisition, Fadama II provides various other benefits to FUGs which may affect the return on investment for irrigation pumps, which will affect the WTI. These benefits include advisory services on production, processing, storage and marketing of agricultural products. Specific to irrigation, the group benefits from advisory services on water management, water conveyance system, and maintenance of irrigation pumps.

Several other programs exist such as the Special Program on Food Security (SPFS), which encourages private farmers' investment in the use of irrigation pumps but with a different approach. Under SPFS, irrigation pumps are bought and distributed to farmers who need them and the cost is recovered from the farmer. While Fadama provides some sort of subsidy, SPFS only serves a facilitation role. The availability of such programs affects farmer's incentives to invest in irrigation pump through Fadama II.

The finding is in line with the literature that says female farmers are as willing as male farmers to invest in irrigation pumps to take up slack season food production (Ogunjimi and Adekalu 2002) and to start a micro-enterprise (Westby et al. 2005). In Northern Nigeria, however, irrigation is still predominantly a male affair (Abubakar 2002) and that tradition may raise the transaction costs for females to access irrigation pumps.

A higher dependency ratio reduces the time available for working-age household members to invest in irrigation pumps. 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 irrigation pump investment as land and irrigation pump are often complementary inputs. Lack of land ownership adds to the transaction cost of obtaining pumps, and therefore, the transaction costs for irrigation investment as the land and irrigation pump are complementary to each other and transaction costs associated with renting the land often translates into the transaction costs for obtaining pumps. Similarly, the access to an irrigation facility seems to significantly lower the transaction costs in the UST model, as farmers are probably more familiar with the qualities and functions of irrigation pumps used by others.

Being a Fadama member seems to lower the transaction costs in areas with lower annual rainfall, because membership enables farmers to benefit from various networks formed through the Fadama projects. Deciding to purchase pumps as a group can also lower the transaction costs for an individual searching 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 a higher total investment through the reduction in transaction costs. Interestingly, farmers who are members of Fadama II in areas with higher rainfall may have higher transaction costs, because farmers in those areas are slightly better off and the opportunity costs of participating in Fadama II activities may be higher.

As expected, the qualitative differences between results from Heckman and the UST models are relatively small. The results from UST, however, still add improvements to Heckman's model in 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)⁶. As in Table 5 and Table 6, an unobserved stochastic threshold model leads to a smaller mean of squared residuals (45.931) than with Heckman (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. Threshold investment level increase by US⁷ \$2,434 for being a female farmer, \$160 with one unit increase of household dependency ratio, \$25 with each kilometer of distance to the nearest town, but reduced by \$932 for owning land, \$2,461 for having access to irrigation facilities, and \$2,468 for being a Fadama II member in a location with 1500 mm of annual rainfall and a 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. More information is needed to assess how the information in Table 7 can be used design policy that will increase investment in irrigation pumps by lowering the transaction costs. Nevertheless, the results

⁶ Cogan (1981) also conducted a similar comparison of the sum of squared residuals).

⁷ US dropped hereafter

show clearly that transaction costs significantly affect farmers' decisions with respect to investment in irrigation pumps.

Table 5. Results from Conventional Models (results of state dummies are omitted)ab

	Selection WTI (1000 Naira)						
	Marginal effect	OLS		Tobit		Heckman	
		Co-efficient	Std .err	Co-efficient	Std .err	Co-efficient	Std .err
Total value of irrigation pump in 2005	.000	.356**	(.175)	.618***	(.119)	.365***	(.107)
Age	-0.000	-.933*	(.416)	-1.091	(.771)	-1.014**	(.430)
Household size	.000	-.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)	-0.000	.305	(.845)	-1.322	(1.580)	.222	(.928)
Dependency	-0.001	2.555	(2.334)	-5.385	(4.690)	2.386	(2.126)
Total expenditure of 2005 (1 / 10,000)	-0.000**	.116	(.084)	-.127	(.083)	.106	(.098)
Total value of asset (Naira)	-0.000	.008	(.007)	.000	(.001)	.008**	(.003)
Land ownership (own = 1)	.0070*	-3.774	(14.772)	62.289***	(21.441)	-1.462	(14.342)
Total rainfed area owned	-0.000	.172	(1.473)	-2.906	(44.819)	.145	(1.246)
Distance to nearest town in 2005	-0.000	-.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	.000	.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 planted with pepper in 2005 (1000 ha)	.000	.660	(2.347)	2.751*	(1.541)	.628	(1.997)
Area planted with rice in 2005 (1000ha)	-0.000	-.475	(2.359)	-2.584	(1.672)	-.386	(2.083)
Area planted with sugarcane in 2005 (1000ha)	-0.000	-.597	(.818)	-.027	(3.226)	-.674	(1.565)
Area planted with tomato in 2005 (ha)	.000*	2.212	(2.802)	1.340	(.883)	2.237	(4.116)
Fadama beneficiary * Rainfall (1000mm)	-.026***	.247***	(.086)	-.095	(.061)	.239***	(.044)
Fadama neighbor * Rainfall (1000mm)	-.009	-.016	(.113)	-.050	(.076)	-.020	(.054)
Fadama beneficiary * Rainfall CV	-.081	.059	(.437)	-.431	(.496)	.058	(.443)
Fadama neighbor * Rainfall CV	-.116	-.174	(.569)	-.695	(.632)	-.247	(.498)
Fadama beneficiary (yes = 1)	.498***	-.234	(.145)	.424***	(.158)	-.208	(.130)
Fadama neighbor (yes = 1)	.0830	.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)
σ_2						46.868	
P						.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	

^aThe asterisks indicate the level of significance level, with *** as 1%, ** as 5% and * as 10%, respectively.

^bThe estimates on state dummies are excluded from the table. All coefficients for Fadama membership and interaction terms were rescaled to 1/1000 to fit in the table.

Table 6. Results from the Unobserved Stochastic Censoring Threshold Model^a

	WTI (1000 Naira)		Threshold	
	Co-efficients	95% CI ^c	Co-efficients	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 rainfed 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 beneficiary * Rainfall (1000mm)	.238	[-.001, 6.53]	.653**	[.1, 1.6]
Fadama neighbor * Rainfall (1000mm)	-.021	[-.511, 4.21]	.127	[-.7, 7.5]
Fadama beneficiary * Rainfall CV	.057	[-5.64, 48.9]	1.338	[-2.0, 3.4]
Fadama neighbor * Rainfall CV	-.247	[-13.1, 12.2]	1.592	[-3.3, 6.5]
Fadama beneficiary (yes = 1)	-.208	[-20.3, .254]	-1.615**	[-5.6, -.8]
Fadama neighbor (yes = 1)	.062	[-10.7, 3.9]	-.525	[-2.6, 2.9]
Receive other financial aid for irrigation pump			-517.767	[-12200, 125]
Intercept	35.717	[-3251, 1064]	898.225**	[60, 20200]
Inverse Mills Ratio	11.684	[-23.4, 71.1]		
σ_1	44.485			
σ_2	394.592			
P	.366			
mean of squared residuals	45.931			
No of observations	160			160

^aThe double asterisks (**) indicate the level of significance at 5%.

^bThe estimates on state dummies are excluded from the table. All coefficients for Fadama membership and interaction terms were rescaled to 1/1000 to fit in the table.

^cThe bias-corrected percentile was used for the confidence interval (CI) since it has relatively 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 transactions 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

Willingness to Invest (WTI)

The results in the UST model indicate that WTI is higher for households with younger people in charge, who received credit in 2005, did not belong to any cooperative, and had no access to a borehole. The Tobit model suggests that WTI is affected by the value of irrigation pumps in 2005, the gender of household heads, land ownership, access to irrigation facilities, and the area planted with pepper in 2005. Fadama membership in more arid regions is not found to be significant in the UST model, indicating that using the Tobit model may significantly distort the factors affecting WTI. Similarly, the Heckman model

suggests a significant effect from the value of irrigation pumps in 2005. However, access to a borehole, Fadama II membership, and rainfall characteristics are not significant in the UST model.

The findings suggest that age is an important factor in a farmer's decision to purchase pumps. Older farmers have a low preference for pumps although they might be labor saving. The reluctance of older farmers to adopt pumps may be explained by their preference for simpler devices like shadouf and their tendency to be risk adverse. Farmers' experience in receiving credit in 2005 is a good indicator of 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 boreholes increases WTI as boreholes can substitute for pumps. Not being a member of a cooperative may also increase WTI since that decreases opportunities for group ownership of pumps or to hire from fellow members.

The findings about the effects of the gender of a household head, distance to the nearest town, and Fadama membership are particularly interesting. Female farmers may face higher challenges to invest in irrigation pump, however, once they invest, they can realize returns as high as those obtained by their male counterparts. Farmers who are located far from the market may also face higher investment challenges but once they invest, they can realize as high a return as their counterparts near the market. Lastly, community-driven development programs like Fadama II can help farmers mostly by lowering the transaction costs of making the investment, instead of by raising the returns to investment.

Conclusion

Investment by African farmers in productive assets, such as irrigation pumps, is affected by the returns to their investments (that is, the profitability of the investment), the availability of financial assistance to undertake such investment, and the transaction costs associated with the investment. While several studies have examined the factors affecting the returns to irrigation technology and much is known about the limited access to credit, little is known about how big the effects of transactions costs are on farmers' decisions to invest, and what factors increase or reduce such effects. Few studies analyze the size of impact of transaction costs on investment in irrigation pump partly because transaction costs are often unobserved or only partially observable and tend to be farmer specific. High transaction costs in Sub-Saharan Africa, however, are considered significant limiting factors for farmers' adoption of modern production technologies. Therefore, it is imperative to identify the extent to which transaction costs discourage farmers' investment in productive technology.

This study applies the Unobserved Stochastic Threshold (UST) model to assess the impact of transaction costs on farmers' investments in irrigation pumps in Nigeria. This study shows that the UST model does not only provide more quantitative information associated with transaction costs than the Heckman and Tobit models, but can also better predict the farmers' willingness to invest in irrigation pumps. Despite this finding, more studies are needed to assess whether the advantage that the UST method has over the other two methods apply more generally. But this study at least indicates that the UST model might be very helpful for assessing the effect of transaction costs on irrigation pump investment in other Sub-Saharan African countries. The UST model may be particularly useful when there is good reason to believe that such transaction costs, and therefore, thresholds vary significantly among individual farmers.

The findings also suggest that the impacts of transaction costs are associated with various socioeconomic characteristics of farmers, some of which do not affect the farmers' willingness to invest. The findings indicate that the threshold can be significantly lowered for farmers who are aware of the potential benefits of irrigation pumps but are discouraged to

invest in them due to the high transaction costs involved. This threshold can be lowered by giving more assistance for female farmers, constructing roads to link farmers to the nearest town, and giving more assistance to community-driven development projects such as Fadama II, especially in the dry Savannah region.

The findings on high transaction costs are very important for Nigeria. Despite Nigeria's irrigation potential, the area under irrigation is only a fraction of the total cultivated area and it has been sustained largely by small-scale private irrigation that is growing but still constrained by the lack of equipments like irrigation pump. The findings in this paper indicate that, while the Nigerian government should continue providing resource to the large-scale public irrigation schemes, the government may also need to help generate an environment that enables farmers to pursue their own private irrigation schemes. The reduction of transaction costs associated with the investment in irrigation pumps is one area in which government assistance can be effective in enhancing the use of irrigation in Nigeria.

The findings in this paper on high transactions in irrigation pump, however, must be interpreted with caution. The findings in this paper only apply to farmers surveyed for Fadama II baseline study, which only covers 12 states out of 37 states in Nigeria. These 12 states may have different irrigation potentials, levels of development in irrigation pump markets, or other agro-ecological and socio-economic characteristics and the results may not represent the conditions in the many other regions within or outside Nigeria. Whether and how the transaction costs affect farmers' irrigation pump investments in other regions must be examined in more studies under regions with different agro-ecological and socio-economic settings. More empirical evidence in Nigeria helps us assess the amount of government assistance needed in each region in order to reduce transaction costs in irrigation pump investment.

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Appendix 1: Lifetime Indirect Utility Function in Rosenzweig and Wolpin (1993) and its Modification

This study builds its farmers' investment decisionmaking model for irrigation pumps on Rosenzweig and Wolpin's (1993). Rosenzweig and Wolpin (1993) provide a good example of the Lifetime Indirect Utility Function which is appropriate for durable production assets such as irrigation pumps, and how the investment decisions for them is derived through utility maximization problems. Rosenzweig and Wolpin (1993), however, considers a more general setting in which farmers make decisions not only about whether to invest in irrigation pumps, but also about how to market their livestock (bullock). The specification of the expected Lifetime Indirect Utility Function (7) is therefore a modified version of Rosenzweig and Wolpin (1993). More specifically, the Indirect Utility Function (7) in this study modifies that of Rosenzweig and Wolpin (1993) in three ways: Excluding the livestock-related part, modifying the investment variable, and including more disaggregated household characteristics. These are more important determinants for investment in irrigation pumps in Africa, where market failure is more serious than in India, the country studied by Rosenzweig and Wolpin (1993). The following describes exact procedures through which (7) is derived from Rosenzweig and Wolpin (1993).

In the specification by Rosenzweig and Wolpin (1993), a farmer's lifetime indirect utility at time t (V_t) is expressed as

$$\begin{aligned}
 & V_t(B_t, d_t, M_t, n_t, n_{t-1}, n_{t-2}, w_t, \varepsilon_t) \\
 & = \max_{\{b_{t+1}, n_{t+1}, m_{t+1}\}} \{u_t(\Pi_t(B_t, M_t, A, w_t, \varepsilon_t) - p^b b_{t+1} - p^m m_{t+1} - c_{n_{t+1}}) \\
 & + .95 \cdot E \max[V_{t+1}(B_t + b_{t+1} + n_{t+2} - d_t, d_{t+1}, M_t + m_{t+1}, n_{t+1}, n_t, n_{t-1}, w_{t+1}, \varepsilon_{t+1})]\}
 \end{aligned} \tag{23}$$

which is a function of Bullock stock at time t (B_t), the bullock death d_t , M_t is a discrete variable indicating the ownership of a pump, n_t, n_{t-1}, n_{t-2} , are the number of calves born at a corresponding time, w_t is the village-level, ε_t is the farmer-level time-varying shock, A is the fixed amount of land owned by the farmer.

From Rosenzweig and Wolpin's (1993) specification of Indirect Utility Function (23), the specification (7) in this study is derived through the following modification;

1. Delete all the livestock-related variables (B_t, b_t, d_t, n_t, p^b)
2. Delete village level shock, w_t
3. Replace the indicator of pump ownership M_t with the value of irrigation pump owned S_t
4. Replace the indicator of pump purchase m_t times the price of pump p_m with the value of irrigation pump made s_t
5. Add fixed transaction costs τ associated with the investment
6. Replace the household assets such as the fixed amount of land owned (A) with more disaggregated types of household assets such as unproductive liquid assets (W), initial endowment of goods k (A_k), external income T factors that affect production technology (Z_q) and the price of goods k including both inputs and outputs (p_k)