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**How Does Ownership of Farm Implements Affect  
Investment in Other Farm Implements When Farmers'  
Liquidity Constraint is Relaxed?**

Insights from Nigeria

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## **INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE**

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## ABSTRACT

Mechanization is a key to agricultural productivity growth in developing countries. Farm implements, ranging from hand tools to draft animals to milling machines to power tillers and tractors, often play complementary roles with each other, and supporting adoption of certain farm implements may also speed up adoption of others. In the absence of credit, insurance, or information, however, such complementarity may be reduced. This study analyzes how the ownership of particular farm implements by Nigerian farmers affected their investment in other farm implements under a project that provided matching grants for the acquisition of various types of farm implements. We found that ownership of certain farm implements increased farmers' investment in the same implements but reduced their investment in other, potentially complementary, implements. We argue that these effects may be partly explained by high operating and maintenance costs associated with the use of farm equipment in these countries. Ownership of farm equipment may provide a good indicator of farmers' potential willingness to invest in the same of different farm equipment. At the same time, a public project supporting farmers' investment in farm equipment should provide financial support not only for the acquisition of farm implements but also for their operation and maintenance.

**Keywords:** agricultural mechanization, complementarity, liquidity constraint, average treatment effect, operating cost, Nigeria

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# 1. INTRODUCTION

Farm power is an important agricultural input used for land clearing, plowing, planting, harvesting, and processing in many Sub-Saharan African (SSA) countries. Increasing use of farm power has often been required for agricultural productivity growth in other regions. Even in SSA countries like Nigeria, where manual labor provides a significant share of farm power, demand is high for mechanized farm power due to aging of farmers and a shortage of labor at the peak production period. Part of the challenge for agricultural mechanization, including tractorization, is farmers' liquidity constraints. Despite the government's continued focus on tractorization in Nigeria, intermediary implements such as hand tools, draft animals, or milling machines may remain feasible alternatives to tractors for increasing the use of power on farms (Mrema, Baker, and Kahan 2008).

Historically, the agricultural mechanization process has typically started with the adoption of improved hand tools, followed by draft animal implement (such as an ox plow), stationary power (such as a milling machine), and finally motive power (such as a tractor or additional draft animal implements that complement stationary power) (Rijk 1999). This adoption sequence indicates that certain farm implements<sup>1</sup> may be complementary to certain others. For instance, the availability of hand tools may speed up the adoption of draft animals. Simple hand tools like machetes, cutlasses and hoes provide farm power for the land clearing or weeding that is necessary to complement plowing of the same plots by ox plow. Similarly, ownership of draft animals may speed up adoption of processing machines, while ownership of processing machines may speed up adoption of tractors or draft animals. Ox plows provide power to plow relatively larger plots, significantly raising the production potential and enabling farmers to exploit economy of scale from investment into processing machines, which can process large harvests. Ownership of processing machines, such as milling machines, enables farmers to increase the shelf life of produce and decrease postharvest losses. This can in turn encourage the adoption of tractors, which provide increased farm power for land clearing, planting, or harvesting. The sequence of adoption of different farm implements described above can be important for agricultural mechanization in SSA. Less expensive implements can be complementary to more sophisticated implements. Supporting the adoption of less expensive farm equipment may speed up agricultural mechanization in SSA countries while also being more feasible from a policy point of view than directly supporting more expensive equipment.

If farm implements are substitutes, however, different forms of support are required for different technologies. Farm implements can be substitutes for each other depending on the shape of production functions. Even when they are not substitutes in their production functions, two farm implements can still be substitutes to farmers who face an imperfect insurance market, incomplete information, and an imperfect credit market (Feder 1982). In an imperfect insurance market, farmers may be averse to the risks associated with using new farm implements and therefore discouraged from investing in them. Farmers faced with incomplete information can be inefficient in their use of new implements. With an imperfect credit market, different farm implements can compete for liquidity not only for their purchase but also for their operation and maintenance. The combination of such market failures, incomplete information, and farmers' aversion to risk may make owners of certain farm implements less likely to invest in other implements even though the implements could be complementary in a more developed market environment.

Ownership of certain farm implements can therefore be an important indicator of a farmer's potential demand for the same or other farm implements, a fact that can help policymakers design effective support for agricultural mechanization. Little empirical evidence, however, exists regarding whether ownership of certain farm implements increases or decreases the demand for the same and other implements. This paper estimates such effects by examining Nigerian farmers' investment in various farm implements. Due to liquidity constraints, demand for farm equipment is often observed only when farmers are provided with an external capital injection. We use an example from the Second National

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<sup>1</sup> Throughout this paper, *farm implements* refers to many types of equipment providing farm power, ranging from hand tools to draft animals to milling machines to power tillers or tractors.

Fadama Development Project (Fadama II) in Nigeria.<sup>2</sup> More specifically, this study analyzes how average treatment effect (ATE) of Fadama II on farmers' investment in hand tools, ox plows, milling machines, and tractors varied based on their prior ownership of these implements.

The Fadama II dataset is appropriate in addressing the research questions raised in this study. It captures farmers' investment under the project in all the aforementioned farm implements as well as their ownership of these implements prior to project participation. In addition, it contains various household characteristics of both Fadama II participants and nonparticipants, which are needed to reduce the self-selection bias in estimating the impacts. We employ an instrumental variable (IV) method to estimate heterogeneous ATE as suggested by Wooldridge (2002), and we estimate equations for investment in hand tools; ox plows; milling machines; and tractors, tractor–plow combinations; and power tillers. Our results indicate that owners of particular farm implements are more likely to continue investing in the same implements and, importantly, less likely to invest in other, seemingly complementary, implements. Market failures for credit and insurance, incomplete information, and liquidity constraints are therefore likely to make farm implements substitutes instead of complements for each other.

The paper makes important contributions to the literature. First, it provides some indicative evidence that market failures and liquidity constraints can limit complementarity among different farm implements, actually making farmers view them as substitutes. Second, it suggests that farmers' ownership of particular implements can indicate higher willingness to invest in the same implements, a fact that can assist with effective targeting under agricultural mechanization policies in SSA countries.

The paper has the following structure. Section 2 provides the conceptual framework and discusses specific conditions relevant to investment in farm equipment. Section 3 describes the data and estimation methodology. Section 4 interprets the results and Section 5 concludes.

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<sup>2</sup> Fadama II was an agricultural development program assisted by the World Bank and African Development Bank, implemented from 2004 through 2009 with the aim of addressing productivity growth constraints in Nigeria. Fadama II operated on the concept of community-driven development, a bottom-up approach that emphasized social cohesion or more inclusiveness in the management of community resources and governance. One of the key components of Fadama II was financial support for acquisition of various productive assets such as farm implements.

## 2. CONCEPTUAL FRAMEWORK

In typical production functions, tractors, power tillers, and draft animals are often substitutes for each other in activities such as plowing, seedbed preparation, harvesting, and transporting (Ali and Parikh 1992). Milling machines are typically complementary to tractors, power tillers or draft animals. These land preparation implements are useful on larger plots, so the return on using them is higher if a milling machine can be used to process the resulting large harvest while minimizing waste. Milling machines are therefore thought of as complementary to tractors, power tillers, or draft animals. In contrast, hand tools, such as hoes and machetes, generally play a supplementary role in various farming activities. They can be used for land clearing, weeding, harvesting, and processing, and are therefore generally complementary to tractors, power tillers, draft animals, and milling machines because of their versatility.

Several studies, however, report more diverse uses of these implements in developing countries. Tractors and draft animals such as cows can be complementary if they can be used for plowing and weeding, respectively (Starkey and Sims 2002). Tractors can also be used for transporting harvest and labor in some situations (Crossley, Chamen, and Kienzle 2009). Both tractors and power tillers can provide good alternatives to conventional motor vehicles on poorer-quality roads over distances of less than 50 kilometers (Ellis 1997). In all of these cases, tractors can be complementary to draft animals, which are used for land preparation. Similarly, both tractors and draft animals such as oxen can be used for threshing rice (Erenstein and Thorpe 2010). Depending on the capacity of the milling machine, the threshing roles of tractors and oxen can make them either complements of or substitutes for a milling machine.

Complementarity and substitutability of technologies are determined also by farmers' characteristics, such as liquidity constraints and degree of risk aversion (Feder 1982). The literature has long analyzed the linkages between complementarity and substitutability of technologies, and the role of credit constraints in farmers' adoption of such technologies (Feder 1982; Feder, Just, and Zilberman 1985; Johnson and Masters 2004). Feder (1982) analyzes the effect of credit constraints with certain assumptions about farm size, nature of risk (by the two-point estimate method), and risk neutrality.

Relatively few studies, however, present more general conditions in which farmers make investment decisions when liquidity constraints are relaxed—a situation particularly relevant to SSA farmers, who often face multiple market failures in liquidity, insurance, and information. We present a simple static model incorporating technical complementarity or substitutability between two inputs, risks associated with each input, and liquidity constraint or relaxation. We then discuss the conditions under which access to one input affects farmers' demand for the other input. Although our focus is on farm implements, we express the model in a general form so that the interplay of the aforementioned factors can be examined more intuitively.

### General Model

A farmer maximizes his expected utility,

$$E [U(\pi)] \tag{1}$$

which is a function of profit  $\pi$ , such that

$$\pi = p \cdot f(x_j, x_k, x_j^0, z, \eta) - c(x_j, x_k, x_j^0). \tag{2}$$

Profit  $\pi$  is the output  $f$  times the output price  $p$ , net of production cost  $c$ . Output  $f$  depends on the quantity of inputs  $j$  ( $x_j$  in addition to initial endowment  $x_j^0$ ) and  $k$  ( $x_k$ ), other exogenous factors  $z$  and production risks  $\eta$ . Production cost  $c$  is generally incurred to purchase  $x_j$  and  $x_k$  quantities of  $j$  and  $k$ , respectively, as well as using  $x_j^0$  quantity of  $j$  and  $x_k$  quantity of  $k$ . Importantly,  $x_j^0$  affects both

marginal products and marginal cost with respect to  $j$  and  $k$  in production function  $f$  and cost function  $c$ . For simplicity, cost  $c$  is assumed to be deterministic with no risk. Finally,

$$c(x_j, x_k, x_j^0) + \theta \leq \Omega, \quad (3)$$

so that costs  $c$  and other subsistence expenditure  $\theta$  cannot exceed the available liquid wealth  $\Omega$ . The market for  $j$  is assumed to be imperfect, so that farmers cannot sell some of  $x_j^0$ . The farmer chooses optimal  $x_j$  and  $x_k$  as the solutions for utility maximization problems (1) through (3). The Lagrange function is then

$$L = E \{ U[p \cdot f - c] \} + \lambda(\Omega - c - \theta), \quad (4)$$

in which  $\lambda$  is the Lagrange multiplier for liquidity constraint. Incorporating  $\lambda$  into the discussion by Koundouri, Nauges, and Tzouvelekas (2006), farmers' demand for  $j$  and  $k$  under the capital injection ( $x_j^*$  and  $x_k^*$ ) satisfies the following first-order conditions:

$$\frac{1}{p} \cdot c_j^* \leq \frac{E[U']E[f_j^*] - \text{cov}[U', f_j^*]}{E[U'] + \lambda} = \mu_j^*, \quad (5)$$

$$\frac{1}{p} \cdot c_k^* \leq \frac{E[U']E[f_k^*] - \text{cov}[U', f_k^*]}{E[U'] + \lambda} = \mu_k^* \quad (6)$$

$$\Omega - c(x_j^*, x_k^*, x_j^0) - \theta = 0 \text{ (assuming interior solution)} \quad (7)$$

where  $(c_j^*, f_j^*) = (\partial c / \partial x_j, \partial f / \partial x_j | x_j = x_j^0 + x_j^*)$  and  $(c_k^*, f_k^*) = (\partial c / \partial x_k, \partial f / \partial x_k | x_k = x_k^*)$  (see Appendix for derivation). The inequality holds if the equilibrium is a corner solution, due to farmers' liquidity constraint. Note that  $\lambda = 0$  when there is no liquidity constraint, and  $\text{cov}[\cdot] = 0$  when there is no production risk associated with the use of inputs  $j$  and  $k$ , or when the farmer is risk neutral, and in that case the right-hand side of equation (6) reduces to  $f_k^*$ , which is the marginal productivity of  $k$ . When  $\lambda = 0$  but  $\text{cov}[\cdot] < 0$  (meaning, when there is production risk and the farmer is risk averse), the term  $\text{cov}[U'(\pi), \partial f_k^*] / E[U'(\pi)]$  is proportional and is opposite in sign to the marginal risk premium with respect to input  $k$  (Koundouri, Nauges, and Tzouvelekas 2006).

The expression  $\mu_k$  can be interpreted as the marginal expected utility of using one more unit of  $k$ , standardized by the output price  $p$ . In a world with a perfect market, no production risks, and no liquidity constraint ( $\lambda = 0$ ), we will have  $\mu_j^0 = f_j^0 = c_j^0 / p$ ,  $\mu_k^0 = f_k^0 = c_k^0 / p$  (where superscript 0 indicates the value of these parameters prior to capital injection) and the external capital injection will have no effect on  $x_k$  and  $x_j$ .

However,  $\lambda$  is positive when the credit market is imperfect and farmers face liquidity constraint. The external capital injection lowers  $\lambda$  as marginal utility from additional liquidity generally decreases. Such a change in  $\lambda$ , as in equations (5) and (6), affects equilibrium inputs demand  $x_j^*$  and  $x_k^*$  depending on the relationships among  $\mu_k$ ,  $\mu_j$ ,  $c_j$ ,  $c_k$ , and  $p$ . Prior to the capital injection, we could have either  $\mu_j^0 - c_j / p = \mu_k^0 - c_k / p$  (marginal net benefit from additional  $j$  is equal to marginal net benefit from  $k$ ) or  $\mu_j^0 - c_j / p > \mu_k^0 - c_k / p$  or  $\mu_j^0 - c_j / p < \mu_k^0 - c_k / p$  due to liquidity constraint and imperfect market for  $j$ . In the event of capital injection,  $x_j^*$  and  $x_k^*$  are determined in such a way that condition  $\mu_j^* - c_j^* / p = \mu_k^* - c_k^* / p$  is maintained (if  $\mu_j^0 - c_j / p = \mu_k^0 - c_k / p$ ) or moves toward  $\mu_j^* - c_j^* / p = \mu_k^* - c_k^* / p$  (if inequality). Typically, marginal willingness to pay is positive but decreasing as more inputs  $j$  and  $k$  are used, meaning

larger  $x_j^*$  ( $x_k^*$ ) lowers  $\mu_j^*$  ( $\mu_k^*$ ). Therefore, if  $\mu_j^0 - c_j/p > \mu_k^0 - c_k/p$ , farmers will invest more in  $j$  from the external capital injection.

### Effect of Owning a Certain Implement on Investment in Another

Our interest is how owning  $j$  ( $x_j^0 > 0$ ) affects a farmer's investment their  $j$  and  $k$  when the farmer's liquidity constraints are relaxed. The ownership of  $j$  ( $x_j^0 > 0$ ) affects the relationship between  $\mu_j^0$  and  $\mu_k^0$  through their effects on  $\lambda, f_j^0, f_k^0, c_j^0, c_k^0, cov[U', f_j^0]$ , and  $cov[U', f_k^0]$ .<sup>3</sup> We can generally assume that marginal productivity is decreasing and marginal cost is increasing around the vicinity of the initial equilibrium (so that the second derivatives of production function  $f$  and cost function  $c$  are negative and positive, respectively, around the initial equilibrium). First, owning  $j$  could raise  $\lambda$  if the farmer who owns  $j$  has high indebtedness due to the loan payment for  $j$ . In this case, owning  $j$  may reduce the investment in both  $j$  and  $k$ .

Greater  $x_j^0$  can raise the economy of scale of  $j$  in two ways. In one way, with greater  $x_j^0, f_j^0$  may be the same at the initial equilibrium but decrease less steeply as  $x_j$  increases. Alternatively, having positive  $x_j^0$  allows farmers to operate in significantly different equilibrium than those with no  $x_j^0$  so that, for example, we can have  $f_j^0(\cdot | x_j^0 > 0) > f_j^0(\cdot | x_j^0 = 0)$ , indicating that the marginal productivity is higher at larger  $x_j$  at the initial equilibrium. In other words, while the production technology (production cost) exhibits decreasing (increasing) returns to scale at the marginal level, it can exhibit increasing (decreasing) returns to scale across different equilibria. Using these conditions, in Tables 2.1 and 2.2 we provide brief examples of how a greater  $x_j^0$  affects the aforementioned parameters.

**Table 2.1—Cases when owning  $j$  (more  $x_j$ ) increases  $x_k$  ( $k \neq j$ ) when there is external capital injection  $\Delta\Omega$**

Key conditions	Explanation	Examples
Low $f_j$ Large $ cov[U', f_j] $	(1) No economy of scale in $j$ (2) Low depreciation rate of $j$ (3) $j$ increases risk	Due to the lack of tractor ( $k$ ), harvest is small and milling machine ( $j$ ) is underused; therefore additional milling machine provides no return.
High $f_k$ Small $ cov[U', f_k] $	(4) $k$ and $j$ are complements (5) Investing in $k$ is not risky	Tractor ( $k$ ) is more profitable if owning milling machine ( $j$ ) raises return from larger harvest.

Source: Authors.

**Table 2.2—Cases when owning  $j$  (more  $x_j$ ) decreases  $x_k$  ( $k \neq j$ ) when there is external capital injection  $\Delta\Omega$**

Key conditions	Explanation	Examples
High $f_j$ Small $ cov[U', f_j] $	(1) Economy of scale from $j$ (2) Depreciation of $j$ (3) $j$ decreases risk	Many farmers bring their harvests for milling for a fee; therefore additional milling machine ( $j$ ) provides additional return. Owning milling machine mitigates the price risk for unprocessed crops.
Low $f_k$ Large $ cov[U', f_k] $	(4) $k$ and $j$ are substitutes (5) Investment in $k$ is risky, requires learning and resources for risk mitigation	Owning milling machine ( $j$ ) requires electricity, cash for operation and maintenance. Allocating resources for milling machine leaves fewer such resources for tractor ( $k$ ), and return for $k$ is therefore lower or riskier.

Source: Authors.

<sup>3</sup> Importantly, in some situations,  $j$  can be used as collateral to improve the creditworthiness of farmers and may relax their liquidity constraints. However, since resale markets for machinery are often underdeveloped in rural Africa, banks usually do not regard used farm implements as reliable collateral.

If the owner of farm implement  $j$  is more likely to invest again in  $j$  and less likely to invest in  $k$ , it is likely that owning  $j$  ( $x_j^0 > 0$ ) either raises  $f_j^0$ , lowers  $|cov[U', f_j^0]|$  and  $c_j^0$ , lowers  $f_k^0$ , or raises  $|cov[U', f_k^0]|$  and  $c_k^0$ . If  $j$  is a milling machine, there may be sufficient economy of scale in investing in another milling machine if sufficient farmers continue to bring in their harvests for processing or if the rate of depreciation is high. Having a milling machine may substantially lower the risk of investing in another milling machine because the farmer is more familiar with how to operate it, where to obtain required inputs to operate it, and what price he receives from either selling processed crops at the market or receiving processing fees from farmers (thus reducing  $|cov[U', f_j^0]|$ ). Having a milling machine may also lower the marginal cost of adding a further milling machine (thus reducing  $c_j^0$ )—which is the cost incurred for purchase, operation, or maintenance—if the new milling machine can use the same facilities and repair service as the old machine. However, the marginal cost may be higher if, for example, the new machine requires new storage space with potentially higher opportunity costs (increasing  $c_j^0$ ).

When the external capital injection is limited so that the credit constraint is still binding, more investment in  $j$  alone will lower the investment in  $k$ , since farmers can invest only a limited amount. In the case of Fadama II, however, it is unclear in what cases the capital injection was small enough to cause such a trade-off between investments in two implements. The ownership of a milling machine ( $x_j^0 > 0$ ) can still lower  $f_k^0$  and increase  $|cov[U', f_k^0]|$  when the capital injection is large enough for the initial investment but not sufficient to cover other costs. Machines like tractors can complement milling machines if they allow farmers to increase harvests and improve the utilization of milling machines, in which case  $f_k^0$  is greater if  $x_j^0 > 0$ . Tractors can, however, be substitutes to farmers who already earn a significant portion of their income from using their milling machines and use most other nonlabor resources, such as electricity or cash, to operate and repair the machine, leaving too few resources for operating tractors (thus a tractor lowers  $f_k^0$ ). Owning a milling machine can also make investing in a tractor more or less costly and risky, affecting  $c_k^0$  and  $|cov[U', f_k^0]|$ .

If owning a milling machine raises processing capacity for the harvest, investment in a tractor may be less risky because all the increased harvests are likely to be processed and can be sold at the market, whereas investment in a tractor may be wasted if no processing is possible. In the former case, the risk is reduced due to reduced risk of harvest loss (reducing  $|cov[U', f_k^0]|$ ). On the other hand, owning a milling machine may shift capital resources such as cash away from tractors and make it more difficult for farmers to repair tractors in the event of breakdown (increasing  $|cov[U', f_k^0]|$ ). Owning a milling machine may not reduce the marginal cost of keeping a new tractor because the two implements may use different facilities, repair services, or sources of spare parts (raising  $c_k^0$ ), compared with the aforementioned case of purchasing a new milling machine.

### 3. EMPIRICAL FRAMEWORK AND DATA

The previous section showed a general conceptual framework to illustrate how the complementarity or substitutability of two inputs in a production function and their production risks affect the demand for both inputs when the liquidity constraint is relaxed. In essence, relaxing liquidity constraints can affect the demand for both inputs. Our empirical framework builds on equations (1) through (7) with more detailed specifications relevant in the context of farm equipment.

In our empirical framework, the profit  $\pi$  is more specifically

$$\pi = p \cdot f(x_1, \dots, x_L, z, \eta) - c(z) - \sum_{k=1}^K [w_k x_k + I_k v_k (1 - \Delta)],$$

$$x_k \leq (\delta_k \cdot \varphi_k + I_k) \underline{x}_k \text{ for each } k = 1, \dots, K, \text{ and}$$

$$\sum_{k=1}^K [w_k x_k + I_k v_k (1 - \Delta)] + c(z) \leq \Omega, \quad (8)$$

in which farmers use  $K$  different farm implements,  $k = \{1, 2, \dots, K\}$ , and farmers have two decision variables,  $I_k$  and  $x_k$ . Variable  $I_k$  equals one if a farmer invests in  $k$ , zero otherwise, and  $x_k$  measures the use of farm implement  $k$ , such as hours of operation. The profit  $\pi$  is determined by total revenue  $p \cdot f$ , net the cost of other inputs  $z$ , and the operating costs per use of each implement  $k$  ( $w_k$ ), as well as, if purchased, the price of  $k$  ( $v_k$ ) summed across all  $K$  implements, which is discounted by the subsidy of  $100 \cdot \Delta$  percent provided by the external capital injection.

Each farm implement  $k$  cannot be used more than its maximum capacity ( $\underline{x}_k$ ). If the farmer already owns implement  $k$  ( $\delta_k = 1$ ), it provides additional capacity of  $(\delta_k \cdot \varphi_k) \underline{x}_k$  for the use of  $k$  in which  $\varphi_k$  discounts the capacity of old  $k$  taking into account its depreciation.

Farmers' expected utility is  $E[U(\pi)] = E[U(\pi(\dots, I_1, \dots, I_K, x_1, \dots, x_K, \delta_1, \dots, \delta_K, \Delta))] = E[U(\pi(\dots, I_1, \dots, I_K, \delta_1, \dots, \delta_K, \Delta))]$ , since the optimal levels of  $x_k$  ( $x_k^*$ ) depend on the optimal value of  $I_k^*$ . The farmer invests in  $k$  if  $E[U(\pi(\cdot | I_k = 1))] > E[U(\pi(\cdot | I_k = 0))]$ . Empirically, we assesses (1) how the probability that  $E[U(\pi(\cdot | I_k = 1))] > E[U(\pi(\cdot | I_k = 0))]$  changes when  $\Delta$  becomes available at some level  $\underline{\Delta}$  ( $0 < \underline{\Delta} < 1$ ) and (2) how such an effect varies given the prior ownership of  $k$  ( $\delta_k$ ) as well as  $\delta_j$  ( $j \neq k$ ). The first effect is expressed as

$$\begin{aligned} \psi_k &= \Pr\{ E[U(\pi(\cdot | I_k = 1))] > E[U(\pi(\cdot | I_k = 0))] \} |_{\Delta = \underline{\Delta}} \\ &- \Pr\{ E[U(\pi(\cdot | I_k = 1))] > E[U(\pi(\cdot | I_k = 0))] \} |_{\Delta = 0}, \text{ for all } k = 1, \dots, K. \end{aligned} \quad (9)$$

The second effects are then

$$\begin{aligned} \Psi_{kk} &= \psi_k(\cdot | \delta_k = 1) - \psi_k(\cdot | \delta_k = 0) \text{ for all } k = 1, \dots, K \text{ and} \\ \Psi_{kj} &= \psi_k(\cdot | \delta_j = 1) - \psi_k(\cdot | \delta_j = 0) \text{ for all } k, j = 1, \dots, K; j \neq k. \end{aligned} \quad (10)$$

We estimate equations (9) and (10) using the data collected for the assessment of the Fadama II in Nigeria during 2005 and 2006. The Fadama II dataset contains rich information on farmers' investment behaviors in all the aforementioned types of farm implements as well as their prior ownership of implements. Fadama II was implemented in Nigeria from 2004 through 2009 with the objective of growing agricultural productivity through a community-driven approach with financial assistance from the World Bank and the African Development Bank. Detailed descriptions of the Fadama II project and

its data are provided in various studies (Nkonya et al. 2008; Takeshima, Adeoti, and Salau forthcoming). One of the key components of Fadama II was financial support for investment by individual project participants in various productive assets such as hand tools, draft animals, milling machines, and tractors or power tillers. Project participants were provided with this financial support in exchange for various activities such as joining local economic interest groups and developing a plan for better management of common resources such as public infrastructure for community development. The project was implemented in 10 local government areas (LGAs) in each of 12 states<sup>4</sup>, both of which had been deliberately selected by the Nigerian government and the World Bank (Nkonya et al. 2008). All farmers in the Fadama II LGAs were therefore eligible for project participation, but it was up to each individual to determine whether to participate or not, depending on the perceived benefits and opportunity costs of engaging in the required activities mentioned above. Some farmers who were eligible for project participation therefore did not become Fadama II members (we refer to eligible farmers who did not participate as *Fadama II neighbors*).

Fadama II data were collected in 2006 by the National Fadama Development Office of Nigeria. Data were collected from sample framework consisting of three strata, namely (a) Fadama II participants; (b) Fadama II neighbors, and (c) respondents living in communities in areas outside the Fadama II LGAs but with socioeconomic and biophysical characteristics comparable to the Fadama II LGAs in the same state, which were also purposively selected by the Nigerian government and the World Bank (Nkonya et al. 2008). For each of 12 state, samples for strata (a) and (b) consist of 25 households, respectively, randomly selected from one Fadama Community Association (FCA)<sup>5</sup> which was randomly selected in each of 4 LGAs, which were also randomly selected from 10 aforementioned Fadama II LGAs, while strata (c) consist of 25 households which were randomly selected from similar FCAs outside the Fadama II LGAs. Overall, 300 samples from each of 12 states were collected except in Taraba state where 450 samples were collected. Out of the total 3750 samples, 928 samples had to be dropped due to missing or erroneous information, leaving 2822 samples used in our analyses.

Table 3.1 presents a summary of the descriptive statistics. Farmers who owned different types of implements in 2005 had similar characteristics in terms of age, dependency ratio, household size, and access to credit. Female farmers were less likely to own farm equipment, particularly draft animals. Owners of tractors or power tillers were generally more educated, more likely to rent the land<sup>6</sup> more likely to be engaged in cropping as the primary activity, and less likely to be engaged in nonfarm activity. Owners of tractors or power tillers, or of milling machines, were more likely to own a storage structure in 2005. Interestingly, milling machine owners tended to be those who were relatively wealthier and who engaged in more nonfarm activity but less cropping.

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<sup>4</sup> The states that participated in Fadama II are three states from the humid forest regions (Lagos, Ogun and Imo), four states from moist savannah (Adamawa, FCT, Oyo and Taraba) and five states from dry savannah region (Bauchi, Gombe, Kaduna, Kebbi and Niger).

<sup>5</sup> Fadama Community Associations (FCAs) are associations of Fadama User Groups, which is a common form of economic interest groups in the aforementioned area selected by Nigerian government and the World Bank.

<sup>6</sup> Though the farm size can be another good indicator, we found the data for farm size in our dataset were not reliable. We therefore used whether the farmer rented or owned the land.

**Table 3.1—Key descriptive statistics**

	All	Farmers who owned these implements in 2005			
		Hand tools	Draft animal	Milling machine	Tractors / tractor–plow combinations / power tillers
Age (median)	42	42	42	40	46
Gender (% female)	29	23	9	26	25
% completed primary education	58	57	49	58	67
% completed secondary education	33	34	29	32	50
Dependency (median)	1.0	1.0	1.4	1.0	1.0
Household size (median)	9	9	12	10	10
% who owned storage structure in 2005	9	11	16	21	21
Household expenditures in 2005 (US\$ per month, median)	238	227	190	522	283
% rented land in 2005	11	13	9	15	33
% received credit in 2005	12	12	13	10	13
% primary activity is cropping	55	68	73	47	88
% primary activity is nonfarm activity	18	11	9	27	0

Source: Authors.

Investment patterns also varied depending on Fadama II membership status and crops grown in 2005 (see Table 3.2). In 2005, 59 percent of the respondents had hand tools. In 2006, 13 percent newly invested in hand tools. Fadama II members were slightly more likely to invest in all implements. Among Fadama II members, ox plows and oxen/work bulls were more popular in the dry savannah region, while milling machines were more popular in the moist savannah region. In addition, while ox plows and oxen/work bulls were more popular for those who grew vegetables in 2005, milling machines were more popular among those who grew root crops in 2005.

**Table 3.2—Investment characteristics: Percent of farmers who invested in each implement**

	2005	2006	Fadama II member (2006)			Root crop grower 2005	Vegetable grower 2005	
			Dry savannah	Moist savannah	Humid forest			
Hand tools	59	13	18	19	20	14	17	21
Draft animals	11	4	9	17	6	1	2	9
Milling machines	4	3	7	5	11	6	7	2
Tractors / tractor–plow combinations / power tillers	1	0.3	1	1	1	1	1	1

Source: Authors.

Applying the method of Wooldridge (2002), we run the following linear probability models (LPMs):

$$\begin{bmatrix} h_i \\ d_i \\ m_i \\ t_i \end{bmatrix} = \beta \cdot \Delta F_i + \Delta F_i \cdot \begin{bmatrix} \gamma_{HH} & \cdots & \gamma_{HT} \\ \vdots & \ddots & \vdots \\ \gamma_{TH} & \cdots & \gamma_{TT} \end{bmatrix} \cdot \begin{bmatrix} H_i \\ D_i \\ M_i \\ T_i \end{bmatrix} + \text{other variables} + \begin{bmatrix} \varepsilon_i^h \\ \varepsilon_i^d \\ \varepsilon_i^m \\ \varepsilon_i^t \end{bmatrix}, \quad (11)$$

in which the dependent variables  $\{h_i, d_i, m_i, t_i\} = \{\text{hand tools, draft animals, milling machines, and tractors or power tillers}\}$  take the value of one if a farmer  $i$  invested in each implement in 2006, and zero otherwise.<sup>7</sup> These dependent variables are each regressed onto whether the farmer  $i$  became a Fadama II member ( $\Delta F_i = 1$  if yes, 0 otherwise), and whether the farmer already owned each of these implements ( $K_i = 1$  if yes where  $K_i \in \{H_i, D_i, M_i, T_i\} = \{\text{hand tools, draft animals, milling machines, and tractors or power tillers}\}$ ), interacted with  $\Delta F_i$ .

Specification (11) is essentially a first-difference model, where the dependent variable measures the new investment between 2005 and 2006, explained by the change in Fadama II project membership status of farmers and other time-variant variables, including the change in eligibility to participate in the Fadama II project ( $\Delta E_i$ ). All the time-invariant variables, including farmer characteristics, are thus dropped from explanatory variables and only included as interaction terms with  $\Delta F_i$  or  $\Delta E_i$ . Variable  $\Delta F_i$  is interacted with a binary variable indicating whether the interviewee grew root crops or vegetables in 2005, respectively, given the significant linkages observed in the descriptive statistics. We also included an eligibility variable ( $\Delta E_i$ ) interacted with various farmer characteristics to control for the possibility that Fadama neighbors indirectly received spillover effects from the project, unlike those outside Fadama LGAs. For example, Fadama neighbors may have benefited from reduced cost for other complementary inputs or better access to other physical capital.

Regressors also include variable  $\Delta E_i$  interacted with farmers' characteristics, such as age, gender, household size, education, storage space, rental status in 2005, use of credit in 2005, and state dummy. These characteristics are assumed to jointly affect the various key conditions discussed in the conceptual framework, such as marginal productivity in relation to the cost of different implements, and Lagrange multiplier for the liquidity constraint ( $\lambda$ ).<sup>8</sup> More farmer characteristic variables are interacted with  $\Delta E_i$  than with  $\Delta F_i$  because the ability of Fadama neighbors to take advantage of such opportunities highly depended on their characteristics. Some Fadama neighbors (for example, higher-income farmers) had more information about the access to such complementary inputs than did others, and therefore their characteristics affected the benefit. In contrast, all Fadama II members received more comprehensive support than nonmembers received, so their ability to benefit from the project depended less on their characteristics. Variable  $\Delta F_i$  is not interacted with the aforementioned farmer characteristics.

The decision to become a Fadama II member may be endogenous to the investment decision, since farmers with higher willingness to invest may be more motivated to participate in the project.<sup>9</sup> We therefore use an IV approach, as used by Takeshima and Yamauchi (forthcoming), and we estimate equation (11) by using the generalized method of moments (GMM) approach, which is efficient when heteroskedasticity is inherent in the LPM.<sup>10</sup> It is more appropriate to estimate equation (11) by GMM-LPM than by a binary model, such as IV-probit, since the estimation of a binary model is complicated when a binary endogenous variable ( $\Delta F_i$ ) is included. Following Wooldridge (2002, chapter 18), the excluded IVs are based on the change in eligibility status ( $\Delta E_i$ ) interacted with ownership of implements in 2005, whether the farmer grew root crops or vegetables in 2005, expenditures in 2005, and dependency. Household expenditures and dependency can both affect Fadama II participation because farmers with lower income and a higher dependency ratio may be facing higher liquidity constraints, but these variables may not affect the investment in farm equipment once the farmers are Fadama II members, making these variables appropriate for excluded IVs.

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<sup>7</sup> Dependent variable is individual outcome and not multiple outcomes as in multinomial logit.

<sup>8</sup> We also tested other public infrastructure, such as distance to nearest market or town, as well as social capital, such as frequency of extension visit. We dropped these variables, however, because membership in Fadama as well as eligibility significantly affected these conditions and also because these variables were missing for a significant number of observations.

<sup>9</sup> Importantly,  $k_i$  is not exactly related to  $K_i$ . For example, even if the farmer owned  $K_i$  in 2005, if he or she invested again in 2006, then  $k_i = 1$ . So  $k_i$  is not endogenous to  $K_i$ , as  $\Delta y_{it}$  and  $y_{i,t+1}$  are.

<sup>10</sup> The error terms  $\varepsilon_{it}^K$  are potentially correlated across equations. We also estimated equation (11) using a three-stage least squares method. Results are qualitatively similar to results from equation-by-equation GMM.

## 4. RESULTS AND DISCUSSION

Table 4.1 presents the estimation results on the determinants of farmers' investment in each farm implement, while Table 4.2 summarizes the key results from region-by-region estimations. Results from first-stage IV regressions are summarized in Table 4.3.<sup>11</sup> In order to check the robustness of the result for the investment in tractors, we ran the rare events logistic regression developed by King and Zeng (1999a, 1999b), which corrects the potential bias from the estimation due to the fact that only 11 out of 2,893 farmers invested in tractors. Estimation was done using the Stata command “relogit” by Tomz, King, and Zeng (1999). The p-values in Table 4.1 for testing under- and overidentification, based on Kleibergen-Paap rk LM statistics and Hansen's J-statistics, respectively, indicate that the orthogonality conditions hold for all equations, and IVs are relevant.

**Table 4.1—Results of IV regressions**

	Hand tools ( <i>H</i> )		Draft animals ( <i>D</i> )		Milling machines ( <i>M</i> )		Tractors / tractor-plow combinations / power tillers ( <i>T</i> )		Rare events logit <sup>a</sup>
	Coef	z	Coef	z	Coef	z	Coef	z	Marginal effect
Fadama	.538**	3.64	.101	.71	.044	.98	.001	.02	
Fadama* <i>H</i>	-.535**	9.15	-.052	1.19	-.033 <sup>†</sup>	1.68	.011	1.04	.012
Fadama* <i>D</i>	.001	.02	.200**	3.06	-.035 <sup>†</sup>	1.82	-.012	1.08	.0005
Fadama* <i>M</i>	-.136*	2.43	-.084**	3.41	.082 <sup>†</sup>	1.83	-.006	.55	
Fadama* <i>T</i>	-.108	.98	-.105	1.27	-.047 <sup>†</sup>	1.75	.100**	4.73	.010
Fadama*Root crops	.157**	2.98	-.043*	2.03	.108**	3.12	.012	1.35	
Fadama*Vegetables	.204**	4.32	.168**	4.77	-.014	.63	.014 <sup>†</sup>	1.71	
Eligibility	-.135*	2.36	-.072*	2.08	-.023	.87	.003	.29	
Eligibility*age	.000	.26	.001	1.10	.001 <sup>†</sup>	1.71	.000	.50	
Eligibility*female	-.114**	4.08	-.039 <sup>†</sup>	1.73	.018	1.41	.005	.83	
Eligibility*household size	-.005**	2.68	.000	.23	.000	.12	.000	.36	
Eligibility*primary education	.018	.87	.001	.07	.005	.42	.002	.54	
Eligibility*secondary education	-.032	1.22	.013	.65	-.002	.17	.003	.66	
Eligibility*storage space	.140**	5.07	-.016	.83	-.022*	1.97	.000	.01	
Eligibility*received credit in 2005	-.053	1.36	.035	.98	.033 <sup>†</sup>	1.81	.006	.79	
Eligibility*rented land in 2005	.052*	2.25	-.011	.73	.016	1.12	-.006	1.33	
Eligibility*state dummy	yes		yes		yes		yes		
Intercept	yes		yes		yes		yes		
No of obs.	2,822		2,822		2,822		2,822		
p-value	.000		.000		.000		.000		
p-value for underidentification test	.001		.001		.000		.000		
p-value for overidentification test	.300		.804		.796		.821		

Source: Authors.

Notes: |z| indicates the absolute z-value of estimated coefficients, based on robust standard errors.

<sup>a</sup>For rare events logit, we present only the marginal effects of *H*, *D*, and *T* because other variables are not our interest.

<sup>11</sup> Results from first-stage regressions are not structural equations (Wooldridge 2002), and the important results are the identification tests which are reported in Table 4.1.

**Table 4.2—Estimates in each agroecological zone**

	Hand tools (H)	Draft animals (D)	Milling machines (M)	Tractors / tractor- plow combinations/ power tillers (T)
	Coef	Coef	Coef	Coef
<i>Dry Savannah (N = 1,130)</i>				
Fadama	.749**	.407*	.014	-.005
Fadama*H	-.640**	-.006	-.032	-.002
Fadama*D	-.070	.086	-.018	-.005
Fadama*M	-.050	-.120*	.015	-.013
Fadama*T	.025	-.194	-.019	.200**
<i>Moist Savannah (N = 944)</i>				
Fadama	.708**	-.072	.301 <sup>†</sup>	.024
Fadama*H	-.508**	-.149**	.089	.025 <sup>†</sup>
Fadama*D	.381 <sup>†</sup>	.209	.034	-.015
Fadama*M	-.223	-.123*	-.045	-.009
Fadama*T	-.131	-.020	-.080	-.024
<i>Humid tropics (N = 748)</i>				
Fadama	-.228	.021	.073	-.028
Fadama*H	-.502**	-.004	.019	.003
Fadama*D	-.141	.246**	-.055	.050
Fadama*M	.047	-.002	.215*	-.014
Fadama*T	-.034	.013	-.024	.047

Source: Authors.

Key implications are the following. Ownership in the previous year of most farm implements encourages farmers to continue investing in the same implements under the external capital injections. For example, owning draft animals in 2005 raises the likelihood of investment in draft animals under external capital injection by 20 percentage points. Similarly, owning milling machines raises the likelihood of investing in another milling machine by 8.2 percentage points, and owning tractors or power tillers raises the likelihood of investing in another of these implements by 10 percentage points. The ownership effect is the opposite for hand tools, which tend to be more durable and inexpensive, so that the owners of hand tools are discouraged from investing again in hand tools.

On the other hand, ownership of certain farm implements in the previous year discourages investment in certain other implements under the external capital injection. Owning milling machines reduces the likelihood of investing in draft animals by 8.4 percentage points, while investing in a milling machine is discouraged if farmers already own hand tools, draft animals, or tractors or power tillers. There is little evidence that owning certain implements encourages investment in others under the external capital injection. These results are fairly consistent when we sort the sample into agroecological zones (Table 4.2).

Results in Tables 4.1 and 4.2 indicate that at least in the short run, owning certain farm implements encourages investment in the same implements and discourages investment in others under the external capital injection. These results indicate that even though farm mechanization may follow the order of hand tools to draft animals to processing machines to tractors in the long run, as suggested by Rijk (1999), this evolution may not be observed at individual farmer level in the short run.

These results provide important insights not only into how investment in certain farm implements is affected by ownership of the same implements and of other implements, but also into the factors causing such behaviors. Despite the high operating costs discussed earlier, farmers continue to rely on particular farm implements, as indicated by the positive signs of ownership of the same implements. The positive signs for same implements indicate that complementarity among different types of farm implements is questionable. Furthermore, as indicated by the negative signs for ownership of other implements, farmers may be facing significant liquidity constraints in operating each type of implement. As was discussed above, the investment-discouraging effect of ownership of other implements may not be because the external capital injection was insufficient, so that investment in one implement competed

with investment in another implement, nor due to the debt from loan payment for implements already owned, since such insufficiency or debt would have also discouraged investment in the same implements.

**Table 4.3—Significant coefficients and their signs from the first stage IV estimation**

	Fadama	Fadama*	Fadama*	Fadama*	Fadama*	Fadama*	Fadama*
		H	D	M	T	root crop	vegetable
<b>Included IVs</b>							
Eligible*H	−**	+**	−*		+†		
Eligible*D	+†		+**	−*			+**
Eligible*M				+**		+**	
Eligible*T	+**	+**	+*		+**		+**
Eligible*root crops						+**	+*
Eligible*vegetables	+*		+**			+†	+**
Eligible*expenditure in 2005	+**	+*				+**	
Eligible*dependency	−†						−*
<b>Excluded IVs</b>							
Eligible	+**	−*			+*	−*	−*
Eligibility*rented land in 2005			+**	−**			
Eligibility*age	+*						
Eligibility*female	+**	+**				+*	
Eligibility*household size	+**	+**		+**			
Eligibility*primary education						−*	
Eligibility*secondary education	+**	+*				+**	
Eligibility*received credit in 2005	+**	+**				+**	+**
Eligibility*storage space		+*		+**	+†	−**	−*
Eligibility*state dummy	yes	yes	yes	yes	yes	yes	yes
Eligibility*agroecological zone	yes	yes	yes	yes	yes	yes	yes
R-square	.333	.469	.541	.617	.895	.567	.522
Shea partial R-square	.008	.141	.452	.513	.467	.461	.378
Partial R-square	.031	.410	.498	.593	.893	.484	.468

Source: Authors.

Notes: Insignificant signs are omitted. H = hand tools; D = draft animals; M = milling machines; T = tractors, tractor–plow combinations, or power tillers.

The importance of such discouragement of investment may also be roughly confirmed by the results in Table 4.4, which shows the crude figure of typical operating costs of processing equipment. These figures refer to processing using not only milling machines but also various other types of implement. Nevertheless, they provide some insight into the operating costs for processing. Among 201 farmers reporting costs for processing, a typical farmer spent \$70<sup>12</sup> for nonlabor costs (fuel, lubricants, water, or chemicals) and had median monthly household expenditures of \$186. Although the cost figures need to be interpreted carefully, they indicate that farmers operating milling machines need to allocate significant liquid assets, such as cash, to operate the machinery. Table 4.4 also shows high labor costs and low expenses on repair service. Low repair expenses may indicate that farmers do not spend sufficiently for maintenance, due to either lack of cash or cost of service, raising the risk of breakdown of machinery. Labor costs may be a less important constraint because it is possible to pay laborers in processed products instead of cash. The high labor costs, however, indicate that operating these machines may not significantly save labor costs, and thus continue to take up the household’s resources.

Similarly, based on data for 492 farmers raising cattle in Fadama II data, a typical farmer raising two cattle incurs \$8 per month for feed, medicines and vaccines, veterinary services, water, artificial insemination, and labor combined. The cost of owning draft animals like oxen or bulls may be similar and appears to be substantially lower than the cost of operating implements for processing. The effects of these costs on liquidity constraints may, however, be larger than they appear, because there are significant seasonal variations in these operating costs, particularly for draft animals. For example, failure to pay for veterinary service or medicine in a certain month could lead to death of an animal and loss of its value as

<sup>12</sup> All dollar amounts are in U.S. dollars.

an asset, while the repair of a milling machine can wait, as long as the machine can sit idle. Operating costs for a milling machine or a draft animal can therefore both be high, and ownership of these assets may constrain a significant portion of the farmer's resources under liquidity constraints.

**Table 4.4—Operating costs for processing equipment in 2005**

	Non-labor costs	Repair service	Labor costs	Household expenditures
Median value (US\$/month)	70	1.4	94	186
Number of observations	201	175	158	201

Source: Authors.

In addition, negative signs are more likely to be due to the liquidity constraints associated with operating costs than due to other potential reasons, such as those listed in Table 2.2. For example, it is not likely that draft animals, milling machines, or tractors offer significant economy of scale for most farmers in Nigeria because realizing economy of scale requires sufficient access to other modern inputs such as fertilizer, irrigation, land, and electricity. Similarly, draft animals and tractors may generally increase production risk because when cultivated area is expanded, it is usually within the same locality, where all plots are subject to similar weather and market risks. Finally, it is unclear whether draft animals, milling machines, and tractors are substitutes or complements in the production function for the farmers in the data. A milling machine is more likely to be a complement to the other two. Draft animals and tractors may be substitutes for each other in land preparation, but as was discussed above, they can still complement each other since there are various other uses for these implements. It is therefore likely that the positive sign of ownership of the same implement is mostly due to a high depreciation rate owing to high maintenance costs or lack of access to repair services.

The positive effect of ownership of the same implement may reflect the commonly understood constraints that limit potential complementarity among farm implements, such as farmers' aversion to risks associated with new farm implements. The negative effect of ownership of other implements indicates that such constraints may be further aggravated by liquidity constraints in operating and maintaining the farm equipment. When farmers own certain farm implements, primarily rely on them for income generation, and face liquidity constraints in operating or maintaining them, they are less likely to invest in other seemingly complementary implements that could potentially raise the marginal productivity of their current implements.

The results of this study have important implications for appropriate design of public support for agricultural mechanization in developing countries like Nigeria. Any public project providing financial assistance for investment in farm equipment can be effective only if it supports the implements that the targeted farmers already own or are using. For example, promoting further investment in tractors among farmers who own milling machines but not tractors may be ineffective even though there appears to be significant complementarity between them.

In addition, it may be ineffective for a government to concentrate its support on tractorization alone, and it may be inappropriate at least in the short to medium term to set agricultural mechanization goals on the number of tractors. The lack of complementarity of milling machines or draft animals with tractors indicates that while support for the former among farmers who already own these implements will speed up investment into these same implements, that will not lead to increased investment in tractors; in fact, it may even slow down such investment. In other words, government support will have difficulty in increasing investment in tractors by farmers who own draft animals or milling machines but do not already own tractors. Effective support for agricultural mechanization may therefore need to carefully target the owners of particular implements and assist further investment in the same implements. At the same time, significant investment is needed in public infrastructure to reduce the operating and maintenance costs of farm equipment by improving and stabilizing the fuel or electricity supply, assisting the development of repair and veterinary services, and boosting the market for spare parts.

## 5. CONCLUSIONS

Mechanization of farming operations is an essential component of agricultural growth because the need for farm power cannot be easily met by other modern inputs. Successful mechanization of agriculture requires understanding the effective mechanization path for different farmers. Historically, there have been commonly observed patterns for the adoption of mechanized farm power (Rijk 1999; Pingali 2007), in which the mechanization typically starts with replacement of hand tools by draft animals, followed by processing machines and then tractors or power tillers. When such patterns are expected, support for agricultural mechanization can start with support for draft animals, with the expectation that it will take less public support to facilitate the subsequent adoption of milling machines and tractors, given the relative affordability of draft animals compared with the cost of milling machines or tractors.

Whether such patterns hold in less mechanized countries, however, depends on the complementarity of all the types of implements and the effects of market imperfection (especially for credit and insurance) in these countries. We found that the mechanization patterns may be more complex in SSA countries. SSA farmers seem more dependent on particular farm implements due to heterogeneous production environments, such as the soil types, topography, and climatic risks that determine the relative efficiency of different farm equipment. Also possibly contributing to these farmers' preference for certain implements is their aversion to risks associated with adopting new farm implements, combined with weak extension systems that limit their ability to learn the operation of new implements. At the same time, due to farmers' liquidity constraints and high operating and maintenance costs due to insufficient or missing markets of electricity, fuel, spare parts, and maintenance services, many owners of certain implements find it optimal to save liquid assets for costs associated with the implements they already own instead of investing in other, seemingly complementary, implements.

Last, this study deepens our understanding of the effect of liquidity constraints on complementarity of agricultural production technologies in low-income countries. Earlier studies have shown that in the presence of imperfect credit and insurance markets, production technologies that are complementary to each other can still become substitutes, whereby adoption of one technology discourages adoption of the other (Feder, Just, and Zilberman 1985; Feder 1982). This study further provides some evidence that when significant operating and maintenance costs are associated with certain production assets, credit constraints can discourage not only the simultaneous adoption of seemingly complementary assets but also sequential adoption of seemingly complementary assets, which is particularly detrimental to effective farm mechanization in developing countries.

## APPENDIX: SUPPLEMENTARY FIGURES

$$\begin{aligned} \frac{\partial L}{\partial x_k} &= E\left[\frac{\partial U}{\partial \pi} \cdot \frac{\partial \pi}{\partial x_k}\right] - \lambda \frac{\partial C}{\partial x_k} = E\left[\frac{\partial U}{\partial \pi}\right] \cdot E\left[\frac{\partial \pi}{\partial x_k}\right] - \text{cov}\left[\frac{\partial U}{\partial \pi}, \frac{\partial \pi}{\partial x_k}\right] - \lambda \frac{\partial C}{\partial x_k} = 0 \\ \lambda \frac{\partial C}{\partial x_k} &= E[U'] \cdot E\left[\frac{\partial \pi}{\partial x_k}\right] - \text{cov}\left[U', \frac{\partial \pi}{\partial x_k}\right] = E[U'] \cdot \left\{ p \cdot E\left[\frac{\partial f}{\partial x_k}\right] - \frac{\partial C}{\partial x_k} \right\} - \text{cov}\left[U', \frac{\partial \pi}{\partial x_k}\right] \\ \frac{\partial C}{\partial x_k} &= \frac{pE[U']E\left[\frac{\partial f}{\partial x_k}\right] - \text{cov}\left[U', \frac{\partial \pi}{\partial x_k}\right]}{E[U'] + \lambda} \end{aligned}$$

Cost is assumed to be deterministic, so  $\text{cov}\left[U', \frac{\partial \pi}{\partial x_k}\right] = \text{cov}\left[U', p \cdot \frac{\partial f}{\partial x_k}\right] = p \cdot \text{cov}\left[U', \frac{\partial f}{\partial x_k}\right]$ . We therefore have

$$\frac{1}{p} \cdot \frac{\partial C}{\partial x_k} = \frac{E[U']E[\partial f / \partial x_k] - \text{cov}[U', \partial f / \partial x_k]}{E[U'] + \lambda}$$

## REFERENCES

- Ali, F., and A. Parikh. 1992. "Relationships among Labor, Bullock, and Tractor Inputs in Pakistan Agriculture." *American Journal of Agricultural Economics* 74 (2): 371–377.
- Crossley, P., T. Chamen, and J. Kienzle. 2009. *Rural Transport and Traction Enterprises for Improved Livelihoods*. Diversification Booklet Number 10. Rome: Food and Agriculture Organization of the United Nations (FAO).
- Ellis, S. 1997. *Key Issues in Rural Transport in Developing Countries*. Report 260. Crowthorne, UK: Transport Research Laboratory. Cited in G. Porter. 2002. "Intermediate Means of Transport: A Review Paper with Special Reference to Ghana." Unpublished report. Department for International Development, London. [www.dfid.gov.uk/r4d/PDF/Outputs/R7575015.pdf](http://www.dfid.gov.uk/r4d/PDF/Outputs/R7575015.pdf). Accessed July 20, 2011.
- Erenstein, O., and W. Thorpe. 2010. "Crop–Livestock Interactions along Agro-ecological Gradients: A Meso-Level Analysis in the Indo-Gangetic Plains, India." *Environment, Development and Sustainability* 12 (5): 669–689.
- Feder, G. 1982. "Adoption of Interrelated Agricultural Innovations: Complementarity and the Impact of Risk, Scale, and Credit." *American Journal of Agricultural Economics* 64 (1): 94–101.
- Feder, G., R. Just, and D. Zilberman. 1985. "Adoption of Agricultural Innovations in Developing Countries: A Survey." *Economic Development and Cultural Change* 33 (2): 255–298.
- Johnson, M. E., and W. A. Masters. 2004. "Complementarity and Sequencing of Innovations: New Varieties and Mechanized Processing for Cassava in West Africa." *Economics of Innovation and New Technology* 13 (1): 19–31.
- King, G., and L. Zeng. 1999a. "Estimating Absolute, Relative, and Attributable Risks in Case-Control Studies." Mimeo, Department of Government, Harvard University, Cambridge, MA, US. <http://gking.harvard.edu>. Accessed July 20, 2011.
- \_\_\_\_\_. 1999b. "Logistic Regression in Rare Events Data." Mimeo, Department of Government, Harvard University, Cambridge, MA, US. <http://gking.harvard.edu>. Accessed July 20, 2011.
- Koundouri, P., C. Nauges, and V. Tzouvelekas. 2006. "Technology Adoption under Production Uncertainty: Theory and Application to Irrigation Technology." *American Journal of Agricultural Economics* 88 (3): 657–670.
- Mrema, G., D. Baker, and D. Kahan. 2008. *Agricultural Mechanization in Sub-Saharan Africa: Time for a New Look*. Rome: Food and Agriculture Organization of the United Nations (FAO).
- Nkonya, E., D. Phillip, T. Mogue, J. Pender, M. K. Yahaya, G. Adebawale, T. Arokoyo and E. Kato. 2008. *From the Ground Up: Impacts of a Pro-poor Community-Driven Development Project in Nigeria*. IFPRI Discussion Paper 756. Washington, DC: International Food Policy Research Institute.
- Pingali, P. 2007. "Agricultural Mechanization: Adoption Patterns and Economic Impact." In *Handbook of Agricultural Economics*, edited by R. Evenson and P. Pingali, 2779–2805. Amsterdam: Elsevier.
- Rijk, A. G. 1999. "Agricultural Mechanization Strategy." In *CIGR Handbook of Agricultural Engineering*. Vol., 3, *Plant Production Engineering*, edited by B.A. Stout and B. Chèze, 536–553. St. Joseph, MI, US: American Society of Agricultural and Biological Engineers.
- Starkey, P., and B. Sims. 2002. "Animal Traction in Cuba: An Overview of Survey Results, Issues and Opportunities." Unpublished report. Cuban Network of Animal Traction, Havana. [www.recta.org/pdf/Starkey-Sims-animaltractionincuba-overview-6Aug03-EN.pdf](http://www.recta.org/pdf/Starkey-Sims-animaltractionincuba-overview-6Aug03-EN.pdf). Accessed July 20, 2011.
- Takeshima, H., and F. Yamauchi. Forthcoming. "Risks and Farmers' Investment in Productive Assets in Nigeria." *Agricultural Economics*. Forthcoming.
- Takeshima, H., A. Adeoti, and S. Salau. Forthcoming. "Measuring the Effect of Transaction Costs for Investment in Irrigation Pumps: Application of Unobserved Stochastic Threshold Model to the Case of Nigeria." *African Journal of Agricultural and Resource Economics*. Forthcoming.

Tomz, M., G. King, and L. Zeng. 1999. ReLogit: Rare Events Logistic Regression, Version 1.1. Harvard University, Cambridge, MA, US. Released October 29. <http://gking.harvard.edu/relogit>. Accessed July 20, 2011.

Wooldridge, J. M. 2002. *Econometric Analysis of Cross Section and Panel Data*. Cambridge, MA, US; London: MIT Press.





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