Are Indian Farms Too Small? Mechanization, Agency Costs, and Farm Efficiency

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Abstract

New panel data from India are used to examine the relationship between farm size and productivity based on a model incorporating agency costs favoring family workers, scale-dependent returns to mechanization arising from the fact that a larger contiguous land area is better-suited for high-capacity machinery, and falling credit costs with owned land. The model provides guidance for imputing the shadow price of labor in the presence of agency costs. Estimates based on appropriately-computed labor shadow prices indicate that while small farms have lower unit labor costs, large farms use substantially less labor per acre, are more mechanized and more efficient.

1. Introduction

Although the generalization has many important caveats, across the world the most efficient and productive agriculture is situated in countries in which farms are family-owned, large-scale and mechanized. However, comparisons of farming productivity across countries cannot easily identify the essential barriers to augmenting farming productivity, as countries differ in their property rights regimes, financial systems, labor markets, agroclimatic conditions and other institutional and environmental features. A vast literature has highlighted, usually one at a time, various market imperfections as constraining agricultural productivity in poor countries. These include, for example, credit market barriers, lack of insurance, problems of worker effort, and labor market transaction costs. However, many of these market problems are not confined to poor countries. Moral hazard and adverse selection afflict credit markets in all settings, and farmers do not have unlimited access to capital anywhere in the world. Nor do family farms in many developed countries use employment schemes that differ importantly from those used in those low -income settings where family farms also dominate. And most farmers in high-income countries do not participate in formal crop, income or weather insurance markets. It is thus unlikely that labor market problems or lack of insurance or even credit constraints, can alone account for the large differences in the productivity of farms across many developed and developing countries.

In contrast to agriculture in most high and some middle-income countries, farming in India, while family-run, is neither large-scale nor, until relatively recently, mechanized. The 2001 Census of India indicates that farming in India is *very* small scale - 68% of farms are less than two acres in size and 95% are less than five acres in terms of owned holdings. Mechanization can be examined using data from a new panel survey of almost 5,000 crop-producing farmers in 17 of the major states of India covering the period 1970-71 through in 2007-8, which we describe and employ extensively below. Figure 1, which portrays the fraction of farms with a tractor, a mechanized plow or a thresher by farm size over the full span of the panel data, shows that mechanization is a relatively recent development in India and now closely related to farm scale. Through the late 1990's less than 10 percent of farms of any size had mechanized equipment and there was very little difference in mechanization rates between small and large farms.[1] In the latest round, however, almost 25% of 20-acre farms are mechanized, compared with 10-11% of farms below 10 acres.

Are small Indian farms efficient? There is a large prior empirical literature using Indian data from the 1970's and 1980's, when mechanization was virtually absent, that has found both more intensive use of labor on smaller farms and a negative relationship between output per acre and cultivated area. This measure of productivity ignores all input costs. When paid out costs are accounted for and profits are calculated valuing family labor at prevailing wage rates, however, small Indian farms are found to be less profitable than larger farms (Carter, 1984; Lamb, 2003). It is not clear that either approach to measuring efficiency is correct. Given that agricultural labor markets in rural India are active it is not reasonable to assume that the opportunity cost of family labor is zero. However, if the opportunity cost of family labor is truly the market wage, it is unclear why the labor-land ratio on small farms is so much higher than on large farms.

One hypothesis for why small farms are more labor-intensive and more efficient is based on agency costs, the need for greater supervision of hired workers compared with family workers, as formalized in, for example, Feder (1985) and Eswaran and Kotwal (1986). However, without direct measures of the magnitude of these costs, almost any allocation of labor to land as well as any differences in use of other inputs such as machines can be justified as efficient.

A further difficulty with the empirical literature on the relationship between scale and farm productivity is that it gives insufficient attention to the endogeneity of farm scale and input use. It is possible that within India smaller farms are located where land is higher quality (Bhalla and Roy, 1988; Benjamin, 1995), where credit markets operate more effectively, or where agricultural conditions generally are more favorable to agriculture. Measurement error in farm or plot size also can bias estimates of per-area efficiency and scale (Barrett *et al.*, 2010; Lamb, 2003). Moreover, land holdings may reflect differences in the capability of farmers. In the absence of a feasible way of experimentally varying ownership holdings or farm scale, empirical identification of scale and credit market effects on profitability and mechanization depends upon the ability to control for multiple sources of unobserved farmer-specific heterogeneity.

[1]These trends are consistent with data compiled from Indian national agricultural statistics on the share of power contributed by different sources in agricultural production by Singh (2006). He documents that the share of total farm power supplied by tractors increased from 7.8% in 1970-71 to 42.5% in 2000-01.

In this paper we address these limitations using new panel data from India at the farm and plot level and a theoretical framework that provides guidance for an empirical assessment of the relationship between farm size and productivity with multiple sources of scale economies. In particular, our model incorporates three factors that can be responsible for a relationship between farm profitability and farm size: (i) the presence of a wedge between the cost of family and hired labor arising from differences in supervisory costs, which advantages small-scale production, (ii) falling credit costs with owned land, and (iii) scale-dependent returns to mechanization arising from the fact that a larger contiguous land area is better suited to the use of labor-saving high-capacity machinery. The latter reflects published specifications of agricultural machinery indicating a substantial positive relationship between the size of machines and their ability to carry out tasks (capacity) and thus save on labor time.[2] Because large machines cannot be efficiently operated on small plots, mechanization creates the potential for positive scale economies, as depicted in Figure A2, which provides photographs of four alternative harvesting technologies for rice.

A key feature of the model is that it provides an exact formulation for imputing the shadow price of labor in the presence of differential agency costs for family and hired labor and thus for estimating farm profits. We show that the relevant opportunity costs of labor varies according to the position of the farm with respect to the labor market (whether hiring-in, working off farm, or neither). Because this position varies by stage of production for a given farm (a household may, for example, hire in labor at harvest time, but exclusively employ family labor for plowing), the construction of an appropriate measure of profits requires not only information on supervision time but also data on input use by agricultural operation and on the participation of family members in the wage labor market. Comprehensive data on inputs by season, typical of many surveys, is not sufficient to cost out labor appropriately.

We identify the effects of changing farm size on profitability and input use by making use of the fact that over the nine-year period between survey rounds almost 20% of households divided and/or received inherited land because a parent died, thus changing ownership and scale

[2]For example, Figure A1 in the Appendix based on information on harvesting combines manufactured and used in India, from Singh (2006), shows a strong positive relationship between the amount harvested per time unit and machine weight for both rice and wheat. Part of the increase in efficiency comes about because the larger harvester covers more rows per unit of time and thus can only be used on larger areas.

for farmers within the same family. We exploit this division to first estimate how supervisory costs vary by family and hired labor. Supervisory cost differentials turn out to be large, leading to almost a doubling in the shadow price of labor when a household hires workers relative to when it employs family workers exclusively and works off farm. Despite this large cost differential and the fact that large farms are more likely to be in the high-cost employment regime, we find that estimated profits per acre, computed based on the theoretically consistent shadow prices of labor, increase when owned land size increases. Profits are also higher on larger plots within the same farm, indicating pure scale effects. Mechanization is responsible for part of this advantage. We also find that a farmer is significantly more likely to use a tractor on his larger plots and that farmers with greater owned landholdings invest significantly more resources in mechanized implements and employ less labor per acre. Large landowners also appear to have a credit advantage, as their efficiency, unlike for small farmers, is unaffected by prior profit shocks.

Finally, our analysis provides estimates of land size effects on per-acre profits across different points in the ownership distribution of land. These estimates enable the computation of farmers' reservation rental price: the rental price per acre of land at which, on average, farmers with a given level of land ownership would be indifferent to a marginal expansion of operational holdings. These estimates, which are in accord with direct information on rental prices and estimated land values, indicate that the implicit demand for renting in land rises sharply with acreage up until about 10 acres, after which it falls. Consistent with these estimates, we show that farmers with small landholdings in India do indeed lease out to farmers with larger landholdings. However, the inefficient distribution of land is not overcome by reverse tenancy as only nine percent of farmers lease land.

2. Model

A. *Labor costs and cultivated area with multistage production*

To emphasize the roles of scale economies arising from agency costs and the technology of mechanization we assume that agricultural production is described by a constant returns to scale production function *g*. To simplify the model without loss of generalizability we assume that production takes place in two stages. Agricultural goods are produced using land, *a*, an agricultural input *f*, and work *e*, carried out by labor and/or machinery, applied in each of the two stages. Thus total output is

(1) $ag(f^*, e_1^*, e_2^*)$,

where the superscript * denotes a per-acre quantity. The agricultural input and work by stage are assumed to be complementary in (1).[3] Per-acre work in stage i is produced using per-acre machinery, k_i*, and per-acre manual labor, l_i*, with the productivity of these factors depending on the plot scale a and machine capacity q

(2) $e_i^* = e_i(a, q, k_i^*, l_i^*)$.

We assume that there is a perfect rental market for machines[4] and that the cost of a given machine is increasing in its capacity according to $c_{ki} q^v$, where v <1.[5] Thus, higher-capacity machines are more costly but machinery cost does not rise as fast as capacity increases. This is one source of scale economies. For the moment we take capacity as given, but optimal capacity choice will play a key role in the analysis below. Per-acre manual labor is provided by both family l_f* and hired labor l_h* and both type of labor must be supervised to be effective so that

(3) $l_i^* = \min(l_{shi}^*/s_h, l_{hi}^*) + \min(l_{sfi}^*/s_f, l_{fi}^*)$,

where s_h and s_f denote the amount of supervisory time needed per unit of manual labor of the respective type. Thus, for example, l_{shi}*, denotes per-acre supervisory time for hired workers at stage i. Consistent with the data, as discussed below, we assume that more supervision is needed for hired than family workers ($s_f < s_h$) and that supervisory time can only be provided by family members.

Total household labor l at each stage is divided between on-farm production, supervision, the production of a stage-specific non-durable household good (e.g., leisure) that is measured in terms of units of labor l_{zi}, and off-farm work l_{oi}. Note that neither of these latter labor quantities are in per-acre terms. Thus the time-budget constraint is

(4) $l_{zi} + al_{fi}^* + l_{oi} + al_{shi}^* + al_{sfi}^* = l$

We assume that there is a market for hired labor and the wage paid per unit of manual labor is w.

Labor can be hired out or in by the family at wage rate w. We now show that w is not the shadow price of labor for any household, given agency costs, and that the true shadow price of

[3]For example, an increase in fertilizer requires more work in terms of the application of fertilizer and results in greater output per acre and thus more harvest labor per acre.

[4]We consider the own-versus buy decision once we introduce a credit market below.

[5]Given further structure that is imposed below we require $\nu < 1$ and $\nu < 2\delta$.

labor can differ for the same household across production stages according to whether the household is buying or selling labor in the market. Household utility is defined over consumption x and the non-durable household good by stage

(5) $$u(x, l_{z1}, l_{z2}).$$

Consumption is financed from agricultural production net of labor, input and machinery rental costs and from the earnings from off-farm work wl_{oi} in each stage

(6) $$x = ag(e_1^*, e_2^*) - ap_f f^* - \sum_i (w_i(al_{hi}^* - l_{oi}) - ap_{ki} q_i^v k_i^*) \ .$$

Households are assumed to maximize (5) subject to (1)-(4) and (6) and the additional conditions that off-farm labor and hired labor must be non-negative. Because the difference in supervisory costs between family and non-family members creates a benefit to on-farm employment of family workers, the non-negativity constraints may bind. In particular, in any stage there are three possible regimes depending on whether the household is hiring in labor, hiring out it's own labor or neither (autarchic).[6] We show in Appendix A that the utility-maximizing marginal return to (cost of) labor time in any stage of production $g_{ei}e_{il}$ is given by

(7) $$g_{ei}e_{il} = \frac{1+s_f}{1-h_i^*(s_h - s_f)} w_i \ ,$$

where $u_{lzi} = \partial u(x, l_{z1}, l_{z2}) / \partial z_i$, $u_x = \partial u(x, l_{z1}, l_{z2}) / \partial u(x)$, $g_{ei} = \partial g(e_1, e_2) / \partial e_i$, $e_{il} = \partial e_i(a, k_i^*, l_i^*) / \partial l_i^*$ and

(8) $$h_i^* = \frac{(u_x / u_{lzi}) w_i - 1}{s_h - s_f} .$$

Let w_i^R denote the shadow price of labor in stage i, which is given by the right-hand side of (7). Equations (7) and (8) imply that the shadow price of labor differs depending on which regime the household is in any stage. In particular:

Regime 1: Off-farm work by family members. When family members work off the farm one unit of time can be transformed into w units of consumption by working an additional day, $u_x / u_{lzi} = 1 / w_i$ and thus $h_i^* = 0$ and

(9) $$g_{ei}e_{il} = (1+s_f) w_i .$$

The shadow price of (family) labor when family members work off the farm is thus $(1 + s_f)w_i$.

[6]The case of simultaneously selling family labor off-farm and hiring labor *in the same stage* is precluded by the condition $s_f < s_h$. In that case it would be more profitable to shift family labor time from off-farm to on-farm work thereby releasing the hired workers, who require more supervision and thus are more costly.

Regime 2: Hired workers are employed on-farm. When hired workers are employed $1 - s_h + s_f$ units of time can be transformed into w_i units of consumption by replacing one unit of hired work by one unit of family work, accounting for differences in supervision costs. Thus, $u_x/u_{lzi} = (1 - s_h + s_f)/w_i$, $h_i^* = 1$, and

$$(10) \qquad g_{ei}e_{il} = \frac{1+s_f}{1-s_h+s_f} w_i .$$

The shadow price of labor is thus $(1 + s_f)\, w_i/(1 - s_h + s_f)$ when workers are hired in, which exceeds the labor shadow price when only family labor is used on-farm and family members are working off-farm.

Regime 3 (autarchy): There is neither off-farm work nor hired workers, $h_i^* \in [0, 1]$. This regime exists because of the cost wedge between family and hired labor. In this case, the shadow price of labor lies between $(1 + s_f)w_i$ and $(1 + s_f)w_i/(1 - s_h + s_f)$, that is, between the shadow prices of the first two regimes.

It is important to note that the three labor-cost regimes pertain to a stage of production. Nothing in the model prevents households from working off-farm in some stages and hiring-in labor during other stages, due to variations in operation-specific on-farm labor demand, and this pattern is indeed what we see in the data. An implication of this variation is that the costs of labor inputs must be evaluated at the level of the stage (operation). When stages are aggregated at the *season* or even annual level, as in most data sets, many farms may be observed to be hiring in and hiring out labor. In such cases it is not possible to correctly evaluate labor costs and thus farm profits.[7] Accordingly, we define profits as revenues minus the cost of inputs evaluated at the appropriate regime- and stage-specific shadow prices. Profits per acre summed over all stages of production are then

$$(11) \qquad \pi^*(a) = g(e_1^*, e_2^*) - p_f f^* - \sum_i (c_i q^v k_i^* + w_i \frac{1+s_f}{1-h_i^*(s_h - s_f)}(l_{fi}^* + l_{hi}^*)) .$$

In Appendix B we show that the land rental reservation price for a household is

[7] For example, if two farmers with the same size farm both, say, work off-farm in stage 1 and hire labor in stage 2, the farmer with the more uniform labor use (inclusive of both family and hired work) across stages will have lower labor costs than the one who uses more labor in stage 2, even if total labor usage for the two farmers is the same and wages do not vary by stage.

(12) $$v = \pi^*(a) + a\left.\frac{d\pi^*(a)}{da}\right|_{h_i^*\forall i},$$

where

(13) $$\left.\frac{d\pi^*(a)}{da}\right|_{h_i^*\forall i} = \sum_i g_{ei}e_{ia}\ .$$

Expressions (12) and (13) indicate that the value to the farmer of renting in an additional unit of land is the profits on that marginal unit plus a term reflecting the increase or decrease in profitability of the farmer's total landholdings arising from how the expansion in acreage affects work per acre. Thus whether there are local increasing or decreasing returns to scale depends solely on the sign of the e_{ia}, that is on whether optimal work per acre increases or decreases with acreage in the different stages. We now consider the source of these scale economies.

B. *Technical scale economies, cultivated land and mechanization*

Thus far we have specified work as an arbitrary function of land, labor and capacity. We now focus on the role of mechanization as a source of scale economies. In particular, we assume that manual labor and machinery services are imperfect substitutes in producing work and that machinery varies by capacity. These assumptions are embodied in the following function:

(14) $$e_i(a, q_i, k^*, l^*) = (\omega_m (l^*)^{\delta} + \omega_k((\phi_i(a) - q_i)qk^*)^{\delta})^{1/\delta},$$

where q denotes the capacity of each machine, and k denotes the number of machines. The advantage of large farms with respect to higher-capacity equipment, stemming from the positive relationship between capacity and the physical size of farm machinery, is embodied in the expression $\varphi_i(a) - q$, with $\varphi_{ia} > 0$.

In determining how scale affects profitability and to highlight the particular role that land-size plays in this structure it is helpful to consider first the stage-specific cost function

(15) $$\tilde{c}_i(e_i^*, a) = \min p_k k^* q_i^{\nu} + w_i^R l^* \text{ subject to (14).}$$

Solving (15) first in terms of q_i yields an expression for optimal machine capacity

(16) $$q_i = \phi_i(a)\frac{1-\nu}{2-\nu}\ .$$

Expression (16) indicates that optimal capacity in a given stage is determined only by area and the elasticity ν of the price schedule and, in particular, is not sensitive to the required total work in that stage. Larger operations will use higher-capacity equipment as long as $\varphi_{ia} > 0$, but an increase in the elasticity of the machinery price with respect to capacity, say due to technical change, lowers machinery capacity particularly for large farmers.[8]

The first-order conditions to the cost minimization problem imply that the ratio of supervisory to manual labor is constant given prices and technologies and that the ratio of machinery to labor services is constant given area, prices, and technologies. Because of this proportionality, we can distinguish between how scale affects the demand for inputs conditional on the amount of work and on how scale affects total input demand by increasing work.

In Appendix C we prove the following:

A. *At the margin*, profits per acre and non-labor inputs per acre unambiguously increase with area for households that hire in or participate in the labor market in every stage of production (employment regimes 1 and 2) because the cost of work per unit area falls and the shadow wage is constant. For households in the autarchic employment regime, per-acre profits and area may rise or fall depending on how fast the shadow price of labor rises with land area.

B. Larger operations may be more profitable or less profitable than smaller operations on a per-acre basis. This is because the scale economies associated with mechanization, which reduce labor use, may be offset by the fact that large farms are more likely to use hired labor than small farms and per-unit labor costs are higher in the labor-hiring regime than in the hiring out regime that is typical of small farmers.

C. The number of machines k per unit area will be increasing in area, for δ sufficiently close to 1. This is because (i) there will be an overall expansion of work, (ii) per-unit labor costs may rise (iii) k is increasing in total work.

D. Whether total expenditures on machinery will rise for $\delta < 1$ as land size increases depends on whether the pricing of machinery is sufficiently elastic to capacity (the magnitude of ν). Regardless of whether the number of machines used per unit area increases or decreases, whether a farmer uses a machine of a given capacity

[8]Note that substituting back into the (14) yields a work production function that is analogous to the CES production function with the exception that the share parameter $\omega_k(\kappa_1\phi(a)^2)^\delta$, where $\kappa_1 = (1-\nu)/(2-\nu)^2$, depends on area.

or greater is rising in area.

E. Larger farms will use less labor per unit area if larger farms use hired labor in more stages of production (higher labor costs) than do small farms and if the demand for work is price inelastic and/or labor and machines are sufficiently good substitutes in every stage or production.

C. *Scale effects, land ownership and credit market imperfections*

In the preceding analysis a was any contiguous plot of land used for an agricultural operation. We have thus ignored the distinctions between the ownership or rental of land, as well as of equipment, and we have also assumed that over the agricultural cycle farmers can freely borrow against harvest revenues at a zero rate of interest. We now allow for the possibility of credit constraints. In doing so, we assume that farmers own their plots of land and also own capital equipment. We first take ownership of both assets as given, and then endogenize the ownership of equipment. To incorporate capital market considerations we assume that farmers borrow b^* per acre to finance agricultural inputs and repay this debt with interest during the harvest period. We assume that the interest rate r on this debt is dependent on the amount borrowed per acre as well as on total owned land area, with farmers who own a small amount of land a obtaining working capital at a higher interest rate than larger farmers. Formally, the per-acre amount that must be repaid in the harvest period is given by

(17) $\rho(a,b^*) = (1+r(a,b^*))b^*$,

where the interest rate r is increasing in b^* and decreasing in owned land. The decrease in interest rates with land ownership might reflect the use of collateral, a requirement of most bank loans in rural India (Munshi and Rosenzweig, 2009). In this extended model, ownership of both land and machinery matters. By assumption owned landholdings reduce the cost of capital. But, while we retain the assumption that there is a perfect rental market for machinery, ownership (versus rental) of capital assets such as machinery also influences production decisions through its effect on the amount of debt that must be incurred to finance inputs. In short, if one owns a productive asset one does not have to finance the relevant rental cost.[9] Or equivalently one can rent the machine to

[9]In principle, a similar argument may be made for family labor. A farmer with less area for a given family labor may have lower need to finance hired labor inputs given area and thus borrow less and face a lower interest cost per unit area. The limitation of this argument is that family labor and dependents of those family workers must be fed throughout the agricultural

other farmers and then use the cash to finance other inputs. Thus letting $o*$ denote the rental value of owned assets

(18) $b* = c(a)e* + p_f f* - o*$.

The farmer's maximization problem with credit market imperfections, restricting attention for simplicity to a single stage, can thus be restated as

(19) $\pi*(a) = \max g(e*, f*) - \rho(a, b*) - (1 + r_0)o*$

where r_0 is the rate of return on savings and is assumed to be less than $r(a,b*)$ for all positive levels of borrowing.

Profit maximization then implies that

(20) $\frac{d\pi*}{da} = -\rho_a - \rho_b c'(a)e*$,

where $\rho_b = \frac{\partial\rho}{\partial b*} = \frac{dr}{db*}b* + 1 + r(a, b*) > 1$ and $c'(a)$ is the change in total cultivation costs, conditional on work. The latter declined with area in the absence of credit market constraints within employment regimes of constant labor costs, as shown in Appendix D. The existence of credit market imperfections, as modeled here, makes more positive the gradient of per-acre profits with respect to owned area relative to cultivated area, for given (or zero) credit costs. This is for two reasons. First, there is a negative effect of owned area on interest rates given input use per acre, $\rho_a < 0$. Second, any savings in cost per unit of work associated with scale lower the amount borrowed, thus further lowering interest costs and raising profitability.

In addition to affecting the input choices of farmers, the presence of credit market imperfections creates another empirical problem in measuring true profitability because of the difficulty of accounting for differences in interest rates and thus the true discounted costs of inputs across households in informal credit market settings. In Appendix D we consider the empirical question of whether it is possible to infer correctly the role of credit market constraints in the relationship between owned landholdings and (true) per-acre profitability when borrowing costs are ignored in computing farm profits. We thus consider the comparative statics associated with *estimated* profits, which exclude interest costs. Estimated profits is the most common measure of profits, and the one we use in the empirical work due to the difficulty of obtaining reliable and consistent measures of interest costs. We show that estimated profits and true profits have a

cycle, which reduces the liquidity benefits of having a large family labor per unit of area farmed.

steeper gradient with respect to scale if there are credit market imperfections

A direct test of credit market constraints can be obtained by examining the returns to owned capital assets using true or estimated profits. The marginal return to capital in terms of true profits is given by

(21) $$\frac{d\pi^*}{do^*} = -\rho_b + (1+r_0) = r(a,b^*) - r_0 + \frac{dr(a,b^*)}{db^*}b^* > 0\ ,$$

while the marginal return to estimated profits is

(22) $$\frac{d\hat{\pi}^*}{do^*} = (\rho_b - 1)(c(a)\frac{de^*}{do^*} + p_f\frac{df^*}{do^*})\ .$$

The observed marginal returns to capital assets in the presence of credit constraints evidently differ depending on how profits are computed. However, it is easily established that when $r(a, b^*) = r_0$, that is when borrowing costs are independent of land ownership and equal to the returns on savings, the marginal return to capital assets is zero for either measure of profits. This is because variation in owned machinery at the margin has no effects on the use of production inputs. Therefore, the finding that there is a non-zero return, in terms of estimated profits, to owned capital assets would reject the hypothesis of perfect capital markets. The finding, moreover, that the return to capital falls with owned land size would provide supportive evidence for the assumption that credit costs decline with owned land.

Thus far we have taken the amount of owned capital assets as given. In practice, farmers both own and rent machinery, and the model incorporating credit constraints can explain variation in equipment ownership even in the presence of a perfect rental market. By the assumption of an effective rental market all farmers face the same equipment rental price. But due to credit market imperfections farmer with different landholdings face different borrowing costs. Given that the rental-equivalent price of owning machinery for one agricultural season depends on one’s own cost of borrowing, individuals with relatively low borrowing cost will be more likely to own machinery and those with higher borrowing cost will rent it. This argument suggests that if, as is assumed in (17), financial intermediaries lower the cost of borrowing for larger versus smaller landowners, then given an active rental market, larger farmers will be more likely than small farmers to purchase rather than rent machinery following the entry of such intermediaries.

3. Data

Our empirical investigation of the relationship between farm size and agricultural productivity uses four types of data from two highly-detailed rural surveys that form a panel. The main data sets are the 2007-8 Rural Economic Development Survey (REDS 2007-8) and the 1999 REDS, both carried out by the National Council of Applied Economic Research (NCAER). The surveys were administered in 17 of the major states of India, with Assam and Jammu and Kasmir the only major states excluded. The two surveys are the fifth and sixth rounds of a panel survey begun in the 1968-69 crop year. The original sample frame was meant to be representative of the entire rural population of India at that time but used a stratified sampling scheme that oversampled larger farms.[10] By the sixth round, the original sampling weights no longer enable the creation of nationally-representative statistics from the later-round data. The data can be used, however, to estimate relationships among variables that characterize behavior in the population.

Both the 1999 and 2007-8 rounds include a village survey that provides information on market prices and financial institutions. The 2007-8 survey also includes a village census, carried out in 2006, of all of the households in each of the original 242 villages in the panel survey.[11] The listing data, which included almost 120,000 households, will be used in the final section to examine land leasing patterns within villages. The survey of sampled households in the 2007-8 REDS took place over the period 2007-2009, and includes 4,961 crop cultivators who own land. The sample of farmers include all farmers who were members of households interviewed in the 1999 round of the survey plus an additional random sample of households. These panel households include both household heads who were heads in 1999 and new heads who split from the 1999 households. There are 2,848 panel households for whom there is information from both the 1999 and 2007-8 survey rounds.

While both survey rounds collected detailed information on inputs and outputs associated with farm production by operation and season, the 2007-8 survey is unique among the surveys in the NCAER long-term panel in that the input and output data were collected at the plot level. There is input-output information for 10,947 plots, with about two-thirds of the plots observed at least twice (two seasons or more). The plot/season data enable us to carry out the analysis across

[10]The oversampling of high-income households is an advantage for this study, given our focus on the relationships among scale, productivity and mechanization, because there is more variation in own landholdings at the upper tail where mechanization is prevalent.

[11]Appendix Figure A3 provides the distribution of own landholdings in the set of sampled villages in comparison to that from the Census of 2001. The figure shows that landholding distribution in the sample villages is skewed to the right relative to the national figures. This is not due to the oversampling of high-income households, but reflects the geographical sampling.

plots in a given season, thus controlling for all characteristics of the farmer, including the input and output prices he faces. The 2007-8 survey also includes retrospective information for each household head on investments in land and equipment, by type, since 1999. This includes information on land and equipment that is sold, purchased, destroyed, transferred or inherited. This information will be used to estimate the determinants of farm mechanization.

Another important feature of the data is that it provides information on the source of changes in landholdings. The primary component of land ownership turnover is inheritance that results from family division - less than 3 percent of farmers bought or sold land over the entire nine-year period. Division most often occurs when a head dies and the adult sons then farm their inherited land. Division sometimes occurs prior to the death of a head, which may result from disputes among family members (Foster and Rosenzweig, 2003). Time variation in the state variables owned landholdings and equipment thus principally stems from household splits. Our identification strategy exploits this source of variation in landholdings.

An important assumption of the model is that the rental of land does not overcome the limitations of scale associated with owned plots. The 2007-8 data indicate that only 4.6 percent of cultivated plots, over the three seasons, are rented (4.9 percent of area). Moreover, the data indicate that in all states of India, except West Bengal, 72% of cultivated land is leased from immediate family members (parents and siblings). This is not unexpected, given the presumed efficiency of cultivating contiguous land area, the practice of partible inheritance that makes it likely that owners of adjoining plots are close kin, and the possible moral hazard issues that might arise in terms of farm maintenance.[12]

4. Supervision costs, the shadow value of labor and the computation of farm profits

A key feature of both the 1999 and 2007-8 surveys is that they provide detailed information on labor use for each of three seasons for each of seven agricultural operations (stages),[13] distinguishing types of labor by whether they are hired, family, permanent, whether supervising, and by gender and age. In addition, there is information on the labor supply of family members off-farm. As indicated in the model, operation-specific information on use of hired labor and supply of off-farm labor is critical for imputing unit labor costs. The surveys also include

[12] In West Bengal, 26% of farmers rent from landlords, and only 7% from family.

[13] The operations are land preparation (plowing, tilling), transplanting/sowing, weeding, fertilizer application, pesticide application, irrigation operation, harvesting.

information on own use of implements by type and the rental of implements, by type. Other inputs include pesticides, fertilizer, and water. We subtract out the total costs of all of these non-labor inputs, including the implied rental costs for own equipment, from the value of output using farm gate prices.

The computation of labor costs requires that we appropriately value labor inputs in order to compute profits. The model indicates that the regime-specific shadow value of labor for each operation i is given by

$$w_i^R(a) = w_i \frac{1+s_f}{1-h_i^*(a)(s_h - s_f)} \tag{23}$$

Thus we need to obtain estimates of how supervision time varies by family and hired labor usage. To obtain the relevant coefficients s_f and s_h we use information on mandays of supervision and gender/age-specific family and hired labor from the 1999/2007-8 panel data to estimate the supervision function:

$$S_{tj} = s_f L_{ftj} + s_h L_{h\,tj} + \mu_j + e_{tj}, \tag{24}$$

where S_{tj}=age/gender adjusted mandays of supervision on farm j in year t, L_{ftj}=age/gender adjusted mandays of manual family labor, $L_{h\,tj}$=age/gender adjusted mandays of manual hired labor.[14] As in the model, we assume that supervision of family and hired labor does not vary by operation, so we aggregate the three types of labor across operations and seasons.

Estimation of (24) by OLS would likely lead to an upward bias in the coefficient on family labor, given that supervision is supplied exclusively by family members. For example, in households where family members prefer less home produced goods (leisure), there may be both more family labor and more supervision time supplied. To eliminate this source of bias, we difference equation (24) across the survey round to eliminate any household-level fixed attributes, such as preferences for work. However, any time-specific shock to family labor supply (e.g., illness) could also lead to an upward bias in s_f relative to s_h. To eliminate this source of bias we use instrumental variables, employing variables that predict changes in the family labor force and hired labor between the two survey rounds.

[14]The adjustments were made using the raw information on total days worked by women, men and children in each operation aggregated using the sample median of operation/gender/age-specific productivity weights provided by sample respondents in the 1999 round of the data.

There are two reasons for a change in the size and composition of a farm's labor force - household division, land inheritance and demographic change. With respect to the first, we take advantage of the fact that over the nine-year interval between surveys 19.9% of farms divided. This not only changes the number of household members but also the amount of owned land and thus labor demand. Accordingly, based on the analysis of household division in India (Foster and Rosenzweig, 2003) we use as instruments variables that predict household splits and the change in landholdings. We also use as instruments variables that predict shifts in the number of adult family members due to ageing, namely the age/gender composition of the household in 1999. The instruments include the number of brothers, head's father's age, whether the head's father co-resided, the number of boys and girls aged<10 and over 5, the number of boys and the number of girls aged>=10 and <15, and household size in 1999; and total inherited land by 1999.

Column 1 of Table 1 reports the estimates of (24) using OLS. These estimates suggest that for each manday of family manual labor, 0.17 mandays of (family) supervision time is applied, larger than the estimate for hired labor. The fixed-effects estimates in column 2, as expected, raise the supervision coefficient on hired labor relative to family labor, but the s_f and s_h coefficients are not very different. The FE-IV estimates, however, which eliminate any biases due to shocks to family labor supply, suggest that hired labor requires substantially more supervision than does family labor: the point estimates indicate that every manday of hired labor requires .6 mandays of supervision time. In contrast, an extra manday of family labor adds only .14 supervision mandays.[15] This substantial gap between s_f and s_h suggests that the expansion of the scale of agricultural operations may significantly raise unit labor costs: the shadow wage formula (23) and the third column point estimates of s_f and $s_{h.}$ from Table 1 indicate that within an operation moving from a regime in which the household employs only family labor and supplies some labor to the market to hiring any labor, doubles the shadow price of labor.

According to (23), to compute unit labor costs for each farm in each year we need to know not only s_f and s_h but for each operation the employment regime of the household (h*). Thus, for each household and operation we created an indicator variable for whether the household was

[15]Table A1 in the Appendix provides the first stage estimates. The diagnostic statistics indicate rejection of the null that the estimates are underidentified.

hiring labor, hiring out family labor or neither (autarchy).[16] To compute the appropriate shadow wage for each operation we used information on operation-specific daily market wages available at the village level in each survey, the estimates of s_f and $s_{h.}$ from Table 1, and the operation specific h*. These shadow wages were then multiplied by the total amount of mandays in each operation.[17] Total labor costs are the aggregates of the operation-specific labor costs. Profits were then computed as output value minus total labor costs less the costs of all other inputs..[18] All values from the 2007-8 round were deflated based on state-specific rural CPI indices to 1999 values.

The doubling of unit labor costs when labor is hired means that how average labor costs are related to land size will depend on how the fractions of the total farm labor force employed in each of regimes 1, 2 and 3 vary by landownership size. Figure 2 provides a lowess-smoothed plot of the relationship between these fractions and owned landholdings in the 2007-8 survey. Figure 2 shows that the fraction of the labor force employed in the regime in which household members are not participating in the labor market as either buyers or sellers of labor is not only small, at less than 10%, but does not vary significantly across the distribution of landholdings. As indicated in the model, the shadow price of labor for that regime is endogenously-determined, but bounded by w^R in regime 1 and w^R of regime 2. To simplify the computation of profits we set the shadow price of labor to be the lower-bound figure so as to make conservative our estimates of scale economies, but it is clear from the figure that the choice of either bound will not appreciably affect the results.[19] The fraction of the labor force employed in low-priced regime 1, however, monotonically falls as landholdings increase, from over 27% among the smallest farms to under 7% for farms of 20 acres. More importantly, the fraction of the on-farm labor force employed

[16]We accounted for hiring out to either the farm or nonfarm casual labor market, including construction employment and employment in any public employment scheme.

[17]Note that in regime 2, the higher operation-specific shadow price for that regime applies to both hired and family labor.

[18]Our profit measure corresponds to 'empirical' profits in the model as it does not include interest costs associated with using credit to pay for inputs.

[19] We will show that our estimates are not sensitive to setting the shadow wage to the upper bound in the autarchy regime. Interestingly, the fraction of operations in the autarchic regime (35-40%) is much higher than the fraction of the labor force employed under the autarchic regime. This difference arises because the autarchy regime is unlikely to obtain when labor demand is high. The harvesting operation, for example, requires substantial effort and hired workers are commonly employed in this stage, even on relatively small farms.

under regime 2 (any hired in labor), which has the highest-priced labor, monotonically rises with land size. In particular, among farms of 20 acres about 88% of the labor force is employed in the high-priced regime, as compared with only 65% for the smallest farms. This means that average unit labor costs are 15% higher on the largest farms compared with the smallest farms.

Given the higher labor costs on larger farms, it would be expected that large farms are less labor-intensive. Figure A4 in the appendix, which provides a lowess-smoothed plot of total per-acre mandays of labor, again adjusted for gender and age, by size of owned landholdings from the 2007-8 survey, confirms this. The figure indicates that the per-acre amount of labor employed on the smallest farms is 5.8 times the amount used on 20-acre farms. Despite higher per-unit labor costs per-acre, total per-acre labor costs on larger farms are thus much lower than those on smaller farms because of the lower-labor intensity of production.

The empirical question is whether the lower labor-intensity of larger farms reflects merely their cost disadvantage as exhibited in Figure 2 or also part reflects their ability to substitute machines for human labor more efficiently. Figure 3 plots four variants of farm productivity by owned landholdings from the 2007-8 survey round. The first two replicate measures commonly used in the literature: gross output value per acre and per-acre profits net of all but the cost of family labor (only paid out costs). The second two are our measures of profits, which take into account regime- and operation-specific agency costs of both hired and family labor, using the lower and upper bounds, alternatively, for labor shadow prices in the autarchy regime.

As can be seen, farm productivity measured by per-acre output first declines steeply with farm size for farms below two acres and then is relatively constant for farm sizes above two acres. This would appear to primarily reflect the uncosted greater intensity of labor use on the smallest farms. As farms below two acres represent 68% of all farms in India, it is not surprising that many studies using this measure of farm efficiency conclude that small farms are more productive. However, a farm productivity measure constructed by subtracting paid costs from the value of output, with thus only family labor being valued at zero, falls with increases in land size only for farms below one acre, representing just 9.8% of all farms in India. Above one acre, there is a monotonic rise in this measure of farm profitability with farm size. When the theoretically-justified costs of family and hired labor are taken into account we see that per-acre profitability rises with land size over the whole distribution of farm sizes, and more steeply with land size compared with the profit measure that excludes family labor in operational costs. Moreover, these measures suggests that profits are negative for farms below one acre when agency and opportunity costs of labor are taken into account. Of course, all of these figures, as noted, are descriptive. To gage whether an increase in land size augments profitability, across the farm size distribution, we need to know how an exogenous increase in land size for a given farmer affect per-acre profits.

5. Owned Landholdings and Profitability

To estimate the causal effect of total land owned as well as owned machinery on per-acre profitability we need to account for the possibility that landownership and machinery are correlated with unmeasured attributes of farmers. We again use the 1999-2007-8 panel data. Prior studies have exploited panel data to eliminate time-invariant fixed farmer and land characteristics such as risk aversion or ability. However, this is not sufficient to identify the effect of variation in a capital asset such as land. The equation we seek to estimate is

(25) $$\pi_{jt} = \mathrm{d}_{0t} + \mathrm{d}_A A_{jt} + \mathrm{d}_k k_{jt} + \mu_j + \varepsilon_{ijt},$$

where t is survey year, k=value of all farm machinery, μ_j=unobservable household fixed effect, and ε_{ijt}=an iid error. Controlling for owned farm machinery, we expect that the coefficient $\mathrm{d}_A>0$ if there are scale effects that permit more efficacious use of farm machines and lower credit costs. The coefficient on owned machinery (d_k) reflects the interest savings associated with ownership, which may be higher for small farms. Estimation of (25) by OLS is not likely to provide a consistent estimate of the effects of either owned machinery or land size. For example, farmers who are unobservably (to the econometrician) profitable may be better able to finance land purchases and equipment, leading to a spurious positive relationship between landholdings, capital equipment and per-acre profits.

Taking differences in (25) across survey years to eliminate the farmer fixed effect, we get

(26) $$\Delta\pi_{jt} = \Delta\mathrm{d}_0 + \mathrm{d}_A\Delta A_j + \mathrm{d}_k\Delta k_j + \Delta\varepsilon_{ijt},$$

where Δ is the intertemporal difference operator. However, in (26), even if the errors ε_{ijt} are iid, investments in capital assets such as land or equipment will be affected by prior profit shocks in a world in which credit markets are imperfect. Moreover, shocks to profits might affect the likelihood of family division. By differencing we thus may introduce a negative bias in the land and equipment coefficients - positive profit shocks in the first period make ΔA_{ijt} high when $\Delta\varepsilon_{ijt}$ is low. That is, even if the contemporaneous cov(ε_{ijt}, A_{jt}) = 0, because assets are measured prior to the profit shock, cov($\Delta\varepsilon_{ijt}$, $_{\Delta aj}$) ≠ 0. We show below that for most farms (small farms) in India there is underinvestment in machinery, relative to what would be expected in the absence of credit constraints, and that past profit shocks affect current variable input use. Moreover, if landholdings and equipment are measured with error, differencing will augment attenuation bias in the coefficients.

To obtain consistent estimates of d_A and d_k we again employ an instrumental-variables strategy that exploits the division of households over the nine-year period as well as land and equipment inheritance. For all heads of farm households in 2007-8, we have information on inheritances since 1999 and for the household heads in the 1999 survey round, we know how much of their owned land and equipment was inherited before the 1999 survey round. The instruments we use to predict the change in landholdings of a farmer between 1999 and 2007-8 are thus the value of owned mechanized and non-mechanized assets inherited prior to 1999 and the value of assets and acreage of land inherited between 1999 and 2007-8. We also again add variables that in our prior study of household division in India (Foster and Rosenzweig, 2002) contributed to predicting household splits and the size of inheritance. Splits, and the inheritance of land, most often occur at the death of the father. We thus include the age of the father in 1999. In some cases, sons choose to split from the family prior to the death of the father/head. Thus, the father of a farmer in 2007-8 may not have been co-resident in 1999, the son already having split. We thus also include a dummy indicating the resident status of the father in 1999. In our earlier study we found that inequality among claimants (principally siblings) was a significant predictor of household division for households in which the father was co-resident. We thus also include a measure of the educational inequality among the claimants to the head's land in 1999 and an indicator of whether the farmer in 2007-8 had brothers.

Appendix Table A2 contains the estimates of the first-stage equations predicting the change in landholdings and the value of farm equipment between 1999 and 2007-8. The Anderson Rubin Wald test of jointly weak instruments rejects the null at the .005 level of significance. Indeed, post-1999 inheritance of land is a significant predictor of the change in landholdings over the period along with the indicator of whether the father was not co-resident in 1999, while inherited assets obtained prior to 1999 and inequality in claimants statistically and significantly affect the change in the stock of equipment.

We estimate two variants of (26), omitting capital equipment in order to estimate the unconditional relationship between landownership size and profitability gross of owned farm equipment and adding the fraction of owned land that is irrigated. We first report estimates for all three specifications using only village and time fixed effects in columns 1-3 of Table 2, where the reported t-ratios are clustered at the 1999 farm level. This estimation procedure roughly, by village area, controls for land quality heterogeneity and prices, but not individual farm heterogeneity. These estimates indicate that larger farms are marginally but statistically significantly more profitable per acre, consistent with Figure 3. The positive profit-farm size gradient is robust to the inclusion of the irrigation and capital equipment variables. The farmer fixed-effects estimates, reported in columns 4-6 of the table, are similar in magnitude to the estimates in which only village fixed effects are included, again indicating a precisely-estimated but small positive effect of owned land on per-acre profits. However, as discussed, these estimates are biased negatively to the extent that there are credit constraints on capital investments.

The last three columns of Table 2 report the FE-IV estimates that eliminate the bias in the farmer fixed-effects estimates. These show that an exogenous increase in landholdings gross of changes in capital equipment also significantly increases per-acre profits, but by a larger amount than indicated by the methods that do not take into account the full endogeneity of land owned. The point estimate indicates that a one-acre increase in landholdings at the mean increases per-acre profits by 9.2%, and this effect appears to be robust to the inclusion of the irrigation share. The (average) marginal return on capital assets is small and positive (1.9%), but only marginally statistically significant. The Kleinberger-Paap and Hansen J diagnostic test statistics, reported in the table, indicate that we can reject the null that the second-stage estimates for either specification are not identified.

Do the estimates indicate that there is an optimal farm size? Or put differently, is there a farm size at which additional increases in owned land no longer increase profits per acre? Figure 4 reports the locally-weighted FE-IV land coefficient d_A by land ownership size ranging from 0.1 to 20 acres along with the associated one standard deviation bands. As can be seen, for all landholdings below 20 acres increases in owned land increase profits per acre, but the effects are substantially larger for the smaller farms and almost vanish among farms of 20 acres. The effects are quite large for the 83% of farms in India below five acres; increasing farm size by one acre would increase per-acre profitability by around 1300-1400 rupees.

If credit costs decline with land size, as we have assumed, the marginal returns to capital should also decline with land ownership size. Appendix Figure A5 reports the locally-weighted FE-IV estimates of the marginal return to capital equipment d_k, along with the associated one standard deviation bands, across the same range of owned landholdings. Marginal returns evidently do decline as landholding increase - for farm sizes below two acres, the return to capital is between .02 and .06, while for farms of 10 acres, the return vanishes. While smaller farms may use an efficient level of machinery given their scale and borrowing costs and the prevailing equipment rental rate, the need to finance these rentals evidently substantially reduces input use and thus profitability. Note that because a major component of the return to own capital is the savings on interest and we have not accounted for interest costs in our measure of profits, these returns to capital are underestimated. This may be one reason that the estimates indicate negative returns to owned capital above 10 acres. Note also that the downward gradient is also underestimated to the extent that interest costs decline with owned land.

In Appendix Table A3 we report estimates that replace our measured profits by (i) profits that employ the upper-bound shadow price of labor in autarchy and (ii) a measure of profits that assumes the shadow price of family labor is zero (uncosted family, but appropriately priced hired labor), respectively. As can be seen, the main finding that increases in landownership size significantly increases profitability per acre is robust to these alternative measures of farm productivity. Indeed, because computed profits are higher when the cost of family labor is not taken into account, the estimated marginal effect of increasing land size is double that pertaining to profits when labor costs are appropriately accounted for, using either the theoretically-justified upper- or lower-bounds on the labor shadow price in the autarchy regime.

6. Farm Size and Equipment Investment and Rental

Appendix Figure A5 suggests that credit costs fall with landownership, given the underinvestment in machinery characterizing small farms. In this section we estimate the effects of landholdings on equipment investment and rental. The model suggests that farms owning more land will purchase more capital equipment to take advantage of scale economies and because they face lower credit costs. For this analysis we use the retrospective information from the 2008-9 REDS that provides a yearly history of land and capital equipment acquisition from 1999 up to the survey interview date. In contrast to the panel data based on information from the 1999 and 2007-8 survey rounds in which the household unit is defined by the households in 1999, 19% of whom split, the unit for this analysis is the household in 2007-8. There are two consequences. First, the sample is larger than the 1999-2007-8 panel, because the latest survey round includes a new random sample of households. Second, if a farmer split from a household after 1999 his owned land and farm assets at the 1999 date is reported as zero if he was not formerly the household head. 25% of the sample farmers in 2007-8 experienced an increase in owned landholdings since 1999, of whom 79% inherited land due to household division. Less than 1.2% of farmers were observed to experience a decline in owned landholdings.

We create a panel data set from the retrospective history by computing any new investments made in farm machinery within the three-year period prior to the 2007-8 interview data and within the three year period 1999-2001. We also compute the stock of equipment and landholdings in 1999 and three years before the interview in the last round. Thus we create two observations on capital investment, landholdings and equipment stock value for each farmer.[20] We also examine the determinants of equipment rental. Here we must use information on the value of hired equipment services in 1999 and in 2007-8 from the 1999 and the 2007-8 surveys, so that the sample size is reduced to the matched 1999-2007-8 panel.

Our model incorporates credit market imperfections as one of the factors that constrain mechanization, with owned landholdings serving to mitigate credit costs. We thus add to the household panel information on bank proximity. From the 1999 and 2007-8 village-level data we created a dummy variable indicating whether a commercial bank was within ten kilometers of the village in which the farm household was located. 84% of farmers were within 10 kilometers of a bank in 1999; the corresponding figure in 2007-8 was also 84%. However, banks were not stationary. 25% of the farmers experienced either the exit of a bank or a newly-proximate bank.

The equipment purchase and hire equations we estimate are thus of the form:

$$K_{kjt} = \mathrm{e}_{0t} + \mathrm{e}_A A_{jt} + \mathrm{e}_k k_{jt} + \mathrm{e}_B B_{jt} + \mu_j + \eta_{ijt}, \tag{27}$$

[20]In principle the data can be used to examine the determinants of net land sales. However, less than 2% of farmers sold or purchased land over the 9-year interval. In contrast, 18% of farmers invested in capital equipment.

where K=equipment purchase or rental and B=bank proximity. We expect that $e_A>0$, $e_k<0$, and $e_B>0$; that is, large landowners are more able to finance equipment purchases and have a higher demand for equipment rental, given their existing stock of farm machinery, while prior ownership of machinery should reduce additional equipment purchases or rental. To eliminate the influence of unobserved time-invariant farm and farmer characteristics (μ_j), we again difference across the two periods and use instrumental variables to eliminate the bias discussed in the previous section. Because a little over half of the observations in the retrospective-based panel are from the newly-drawn sample of households in 2007-8, we cannot use information on family circumstances in 1999 as instruments, which is only available for the 1999-2007-8 panel. We use as instruments for the change in owned landholdings, the change in the value of farm equipment and the change in bank presence, the value of farm assets inherited since 1999, the amount of land inherited since 1999 and bank proximity in 1999.

The estimates of (27) are presented in Table 3; the first-stage estimates are presented in Appendix Table A4. Again, the estimates pass the standard diagnostics tests. Inherited land is a statistically significant predictor of the change in owned landholdings, inherited assets are statistically significant predictors of the change in the value of the stock of machinery, and bank presence in 1999 is a statistically significant predictor of subsequent bank location.

The first column of Table 3 reports fixed-effects estimates of the determinants of machinery investment that do not use the instruments. While the signs of the coefficients are as expected, the precision of the coefficient estimates is low for both land and the equipment stock. When instruments are used, however, as reported in the second column, both the capital equipment and land coefficients increase substantially and become statistically significant. In particular, an increase in owned landholdings increases equipment investment, given the existing stock of equipment, while for given landholdings, those farms that already own equipment invest less. The effect of bank presence also appears to contribute positively to equipment investment.

The estimates in columns four through six in Table 3 for equipment rental parallel those for equipment purchases, except that bank presence is negatively related to rental. Larger farms owning less equipment rent higher amounts of power machinery. The positive bank coefficient in the equipment purchase equation and the negative coefficient in the equipment rental equation may reflect the fact that banks are less likely to finance variable input costs. Thus, where banks are proximate, the cost of equipment ownership is low relative to that of machinery rental.

7. Identifying Scale Effects

The panel-data estimates of the effect of owned landholdings on profitability reflect, as noted, not only scale economies associated with the use of a higher-capacity (or any) mechanized inputs but also lowered credit costs and augmented labor input costs. In this section, we identify the effects of scale net of both labor cost effects and credit cost effects, by estimating how variation in the size of plots for a given farmer in a given season affects plot-specific per-acre profitabilty and input use. Over three seasons we have 16,544 observations on owned cultivated plots for 7,845 farmers in the 2007-8 survey round. By using farmer/season fixed effects we are holding constant input prices inclusive of the shadow price of labor as well as total owned assets and access to credit. The effects of variation in plot area thus predominantly reflect only scale economies associated with the more efficient exploitation of mechanization on large plots..

Cross-plot, within-farmer/season estimates can be biased, however, if owned plot sizes are chosen by farmers and plots vary by unmeasured characteristics that affect productivity. With respect to plot size, the data indicate that a farmer's ownership holdings consists mainly of parcels of inherited land.[21] A plot is a contiguous area of land that a farmer considers to be the basic unit of farming. Three-quarters of plots consist of a single parcel; the rest are sets of contiguous parcels. Plots are thus almost always sets of inherited parcels that are contiguous, as in less than 4% of cases is a contiguous parcel broken into more than one plot. The median distance between plots is 400 meters. Plot size is thus principally determined by the location and configuration of the farmer's inherited parcels of lands.

The data also indicate that plots differ in soil quality. The survey includes seven characteristics of plots. These include depth, salinity, percolation, drainage, color (red, black, grey, yellow, brown, off-white), type (gravel, sandy, loam, clay, and hard clay) and distance from the farmer homestead. We are thus able to control for plot characteristics.

To identify scale effects from the plot data we estimate the equation

$$\pi_{ijt} = \mathrm{b}_{0j} + \mathrm{b}_{\mathrm{A}} A_{ijt} + \mathrm{b}_I I_{ijt} + \boldsymbol{X_{ij}}\mathbf{a}_x + u_{ijt}, \tag{28}$$

where π_{ijt}=profits per acre on plot i for farm j, b_{0j}=farmer/season fixed effect, A_{ijt}=plot area

[21] 96% of owned parcels were acquired, principally through inheritance, from an immediate family member or grandparent.

(acres), I_{ijt}=whether the plot is irrigated, $\boldsymbol{X}_{ij}$=vector of soil and location plot characteristics, and u_{ijt} is an iid error. The interpretation of the coefficient on plot area b_A is straightforward - it is the effect of scale on profits. However, as noted by Lamb (2003) and Barrett *et al.* (2010), measurement error in plot size biases the own size coefficient negatively. Thus, we will get a lower-bound estimate of scale.

The first column of Table 4 reports the estimates of equation (28) without the inclusion of the seven plot characteristics. The second column reports estimates with the plot characteristics included. In both specifications, the estimates are consistent with the operation of scale economies - larger plots, given the farmer's total ownership holdings, capabilities, preferences, and within a labor-cost regime, are associated with higher profits per acre, despite the negative bias induced by measurement errors, a finding consistent with Barrett *et al.* (2010), who also exploit variation in plot sizes to estimate scale effects.[22] The estimates of scale effects obtained from plot size variation for a given farmer are about 25% lower than the statistically-preferred FE-IV estimates of land size effects on profits obtained from the panel. Because the panel estimates of land size effects reflect both agency and credit costs, while the within-farmer estimates do not, the set of estimates suggests that the negative agency cost effects from increasing scale are more than offset by the decrease in credit costs.

Are the cross-plot profit estimates consistent with scale effects associated with mechanization? We further explore this question by exploiting the spatial variation in the presence of a tractor rental market and by looking at how plot size affects the likelihood of using a tractor. Formal tractor rental markets were in place in 36.4% of our survey villages in 2006, such that there was an established rental price for tractor use. If mechanization accounts for the estimated effect of scale, then the presence of a formal tractor rental market should augment the effect of scale on profits.

The third column of Table 4 reports estimates of equation (28) with an interaction term between plot size and the presence of a formal tractor rental market. That coefficient is positive

[22]Many investigators use output value per acre to measure productivity. Assunção and Braido (2007) employ a similar cross-plot methodology based on ICRISAT data that indicates a negative relationship between per-acre output value and plot size, net of a farmer fixed effect and multiple measures of plot characteristics. However, measurement error biases negatively the coefficient. In our data, the relationship between own plot size and output value per acre is positive, small and statistically insignificant.

and significant at the .045 level, one-tailed test. In columns four through six we replace per-acre profits by a dummy variable taking on the value of one if a tractor is used on the plot. By using a dummy variable, we avoid the ambiguity, as discussed in the theory section, that may arise because the quantity of machinery use may decline with scale as machine capacity rises. The estimates, with and without plot characteristics included, indicate that, consistent with the notion that too small a scale inhibits efficient use of mechanization, a tractor is significantly more likely to be used on a larger plot; the effect of plot size on whether or not a tractor is employed is also higher in villages with an active tractor rental market, but the effect is not statistically significant. Finally, in columns seven through nine we see that total labor costs per acre mirror the effects of scale on plot-specific tractor use - larger plots use less labor per acre and the reduction in labor use on larger plots is significantly stronger where there is a formal tractor rental market.[23]

One aspect of cultivation that is ignored in these estimates is crop choice. It is possible, for example, that higher value, less-labor intensive and more easily-mechanized crops are planted on larger plots. To assess if our results hold up for a single crop, we restricted our analysis to plots cultivated with rice. This restriction cuts the number of plot/season observations by 70%. However, as seen in Appendix Table A5, the results are almost identical to those obtained using all crops - the positive effects of plot size on profitability and negative effects on labor-intensity are highly statistically significant and the point estimates are almost identical in magnitude to those obtained using information on all crops. Indeed, the effect of plot scale on tractor use is stronger for rice plots, but the estimate is not as precisely estimated as in the larger sample.

8. Credit market imperfections, size, and the effects of profit variability

In the preceding section our estimates of credit market effects assumed that the amount a farmer borrowed reflected only his demand for inputs and his ownership of equipment, ignoring own savings as a source of liquid capital. In this section we consider the role of landholdings in determining profitability in a dynamic setting in which profits are stochastic and liquid capital, or cash on hand, affects input allocations when credit market imperfections are in place. In this setting, if there are credit restrictions a farmer who has particularly high profits in one period may be able to finance more inputs and thus accrue greater profits in a subsequent period. If he has

[23] Measurement error in plot size biases negatively the effect of plot size on labor use. In Foster and Rosenzweig (2010) we report FE-IV estimates of landholdings on per-acre labor costs based on the panel data that indicate larger landholdings reduce labor costs per acre significantly.

access to large amounts of capital at market rates no such effects should be observed.

There are other reasons, however, why there may be a correlation in profits across time for a given farmer. For example, it is well-known that fertilizer use increases nutrient levels in the soil that persist over time. This persistence will influence fertilizer use and thus profitability in a subsequent period. Because past fertilizer use will augment past profitability, one might observe a negative correlation between past profits and current fertilizer use. Inattention to dynamic nutrient effects might lead to the false conclusion that credit constraints are unimportant even if credit imperfections were present. Removing farmer and/or plot specific fixed effects from estimates of a profit equation may remove fixed aspects of soil quality that affect profits but will not control for the effects of lagged nutrient shocks. In Appendix E, we use a simplified version of our model to show, in the context of a forward looking dynamic optimizing model how a shock in period *t* affects input use and profits in period t+1.

To separate out credit effects from dynamic nutrient effects we exploit the fact that we have plot-level data on multiple plots for each farmer over three consecutive seasons, which allows us both to control for all unobserved plot characteristics and to separate the effect of a crop shock on liquidity from the effect of the shock on soil nutrients. We augment the dynamic model in Appendix E by letting cash on hand depend on the unanticipated deviations in the across-plot average shock so that $h_{t+1}* = h_t * + \delta(\overline{\theta}_t - E_t\overline{\theta}_t)$. The key distinction is between lagged profits and fertilizer use on a given plot and lagged profits on all other plots. The coefficient on the lagged profits specific to a plot will capture the combined nutrient and (a small fraction of) liquidity effects; the coefficient on the lagged profits from other plots will only reflect the liquidity effect. To identify the latter, we use a subsample of farmers who cultivate at least two plots over three seasons, and we also control for previous period own use of fertilizer on the plot, as lagged fertilizer use will be correlated with lagged profits and will have an effect on current profits due to nutrient carryover.

To see how liquidity effects differ by owned landholdings, the within-plot, cross season estimates, are reported in Table 5 for three categories of farmers - farmers with total holdings below four acres, those with owned land between four and less than 10 acres, and those with holdings of at least 10 acres. The estimates are strongly consistent with the notion that liquidity shocks affect input use and thus profitability among smaller farmers. In particular, conditioning on prior-season profits and fertilizer use on a given plot, a 1000 Rupee decrease in profits per acre on a farmer's other plots in the previous season leads to a substantial and statistically significant 85 Rupee decrease in profits per acre among farmers with less that four acres of land. Among farmers with 4-10 acres of land the corresponding figure is approximately the same, but less precisely estimated, but among the largest farmers (10+ acres) the estimate is essentially zero. In contrast to the lagged farm-level profit effects, the corresponding coefficients for prior-period plot-specific profits are negative, as expected, and in contrast, do not decline in absolute value across farm sizes, consistent with the idea that the own profit effect is mainly a technological effect (in this case nutrient depletion) that is constant across landholdings.

The Table 5 estimates are based on a more or less arbitrary division of farms by size. Figure A6 in the Appendix provides the locally-weighted lowess estimated relationship between the lagged profits of other plots on current own plot profitability across the full distribution of farm sizes up to 20 acres based on the same specification as seen in Table 5. As can be seen, the effect of a liquidity shock on profitability is substantially higher on small compared with larger farms. For farms of two acres, a 1000 rupee decrease in profits the previous season reduces current profits by 105 Rupees but by 85 rupees for farms of 19 acres.

9. The Reservation Rental Price, Landholdings and Rentals

In this section we use our estimates of the marginal effects of land size on per-acre profitability by ownership holdings, displayed in Figure 4, and our estimates of average per-acre profitability by land size, in Figure 3, to compute the reservation rental price (RRP) by land size, using the formula given by (12). In principle, any nonzero relationship between land size and the RRP indicates an inefficient distribution of land, and the specific shape of the relationship is informative as to how a redistribution of land, by specific land categories, would affect overall farm efficiency. Another use of the estimated RRPs, however, is to assess the external validity of our framework. We do this (i) by comparing our estimates of RRP to rental rates and estimated land values provided in the village-level data and (ii) by ascertaining if the relationship between our RRP and land size are in accord with observed land rental behavior.

As seen in (12), the reservation rental price for a farmer in the presence of returns to scale has two components: a component reflecting the profitability of the additional unit of land and a second component indicating how an additional unit of land raises profitability on the property as a whole by increasing scale. Figure 3 indicates that average profits per acre increase sharply for small farms and then level off, while the marginal scale effect on per-acre profits is highest for the small farms (Figure 4) and declines to zero. On this basis it is not obvious whether the RRP rises or falls as owned landholdings increase. It is possible that the benefits in terms of scale economies are so large for small farms that they are willing to pay higher rents for additional land than larger farms even though their average profits per acre are smaller.

Figure 5 plots the estimates of the RRP by owned landholdings. There is evidently substantial variation in the return to land. In particular, the reservation rental rate rises from close to zero for the smallest farmers to just under 15,000 Rs per acre at 12 acres and then begins to decline, reaching 8,000 Rs per acre for farms of 20 acres. Amalgamation of land, for example, to 12 acres, barring any general-equilibrium effects, would evidently increase overall agricultural efficiency by this metric.[24]

How credible are the estimates of the RRPs? We first compare our estimated RRP figures, which are calculated without reference to data on land prices or rental rates, to the range of village rental rates and land prices reported in the 2007 village-level data of the survey. The estimated average RRPs are quite close to the observed prices. The average reported rental rate per acre of irrigated land is 7,255 Rs and that for reported rental rates of non-irrigated land is 4,787 Rs. Average reported land prices are 221,683 Rs and 101,426 Rs for irrigated and unirrigated land, respectively. Annualized at a 5% interest rates this yields implied rental prices of 11,084 Rs and 5,071 Rs, respectively.

With respect to renting behavior, the shape of the RRP trajectory in Figure 5 suggests that the gains from renting in are higher for large than for small landowners, so we should expect to observe small owners renting out land to larger farmers. One should not expect that leasing markets will totally offset differences in land rental rates. Leasing, for example, does not

[24]General-equilibrium effects from a large scale re-distribution of land may be important. For example, because larger farmers use less labor per acre, expanding the size of this group will, *ceteris paribus*, lower the wage. This fall in wages would in turn principally benefit smaller farmers who use labor more intensively. Moreover, the computed RRPs incorporate a model of utility- maximizing behavior but do not incorporate, for example, a preference *per se* for holding land or risk aversion in the context of incomplete insurance markets. Thus while the variation in the RRP by land size reflects inefficiency in terms of the allocation of factors of production, it does not necessarily imply that appropriately compensated transfers of land towards large farms would be Pareto-improving.

generally solve credit market issues for smaller farmers. Moreover, given that scale economies arise in part from contiguous land, as our plot-level findings indicate, the opportunities for productive trade given ownership holdings appear to be small. This is reflected in the fact that less than 10% of farmers lease and most rental contracts are between family members.[25] However, the 2006 village listing data, which provides information on landownership and rental for all households residing in the sample villages, provides a large enough sample size (almost 120,000 households) to examine the distribution of this relatively rare event across farms stratified by ownership size to assess if Indian farmers seek to exploit scale economies.

The relationship between ownership holdings and the probability of leasing in and leasing out in the 2006 listing data, net of village fixed effects that characterize the relevant supply of existing land plots, are shown in Figure 6. The figure strongly supports the hypothesis that leasing goes in the direction of capturing scale economies that are embodied in the estimated rrp's; that is, reverse tenancy. In particular, relative to a household that is 5 acres below the village mean a farmer with 5 acres above the village mean has .018 (over 50%) higher probability of leasing in and a .014 lower probability of leasing out. Leasing behavior thus tends to consolidate landholdings and results in a larger average scale of operation in Indian agriculture. This, according to our estimates, increases average efficiency.[26]

10. Conclusion

It has long been thought that due to the cost advantage of managing and recruiting family labor, small farms in low-income countries are more productive than their larger counterparts. In the context of India, there is a large body of evidence derived from data from the 1970s and 80s indicating that small farmers do achieve relatively high output per acre. While those studies that have tried to look at the relative profitability of small farmers have provided mixed results, none have employed a theoretically coherent method for measuring or adjusting for the differential costs of hired and family. In addition, most empirical studies were undertaken before the rise in

[25]As we have noted land sales in our panel data are too scarce to characterize patterns by ownership size. The data do suggest, however, that land sales too are predominantly intrafamily - 95% of the land sales that took place between 1999 and 2007 are from parent to child.

[26]Rawa (2001) concludes from his review of studies of land sales and purchases in India that in general land sales also transfer land from small to large landholders. In his own study of two villages in West Bengal, this pattern was reversed, but this was due to the imposition and lowering of land ceilings and tenancy legislation that required large landowners to sell their land.

mechanization in rural India that accompanied the economic reforms in the mid 1990s. In this paper, we derived a framework for assessing the effects of farm size on productivity and measuring profitability that incorporates agency costs, credit constraints and scale economies arising from mechanization. This framework was applied to unique panel and plot-level data from rural India. We found that despite an almost two to one cost disadvantage per unit of work arising from supervisory-cost differentials for family and hired work, larger farmers have higher profitability per acre and, up to about 10 acres, a greater return to acquiring land than their smaller counterparts. Our evidence indicated that this profit advantage of larger farms arises both from scale-dependent mechanization, which displaces labor, and from lower capital costs and better protection from adverse income shocks.

Our estimates of the positive relationship between reservation land rental rates and owned landholdings are consistent with observed tenancy and sales data from India whereby small farmers transfer land to larger farmers in the absence of program interventions or policy restrictions. However, both tenancy and land purchases and sales are evidently insufficient to equalize the large disparities in returns to land across the land distribution that we find. The low incidence of both tenancy and land sales in the face of large differences in the returns to land investments suggests that there are significant barriers to land amalgamation in rural India. Our findings thus suggest that understanding the source of these impediments might have large payoffs in terms of improving agricultural efficiency in India.

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Figure 1. Proportion of Farms with Mechanized Farming Equipment, by Owned Landholdings and Survey Year

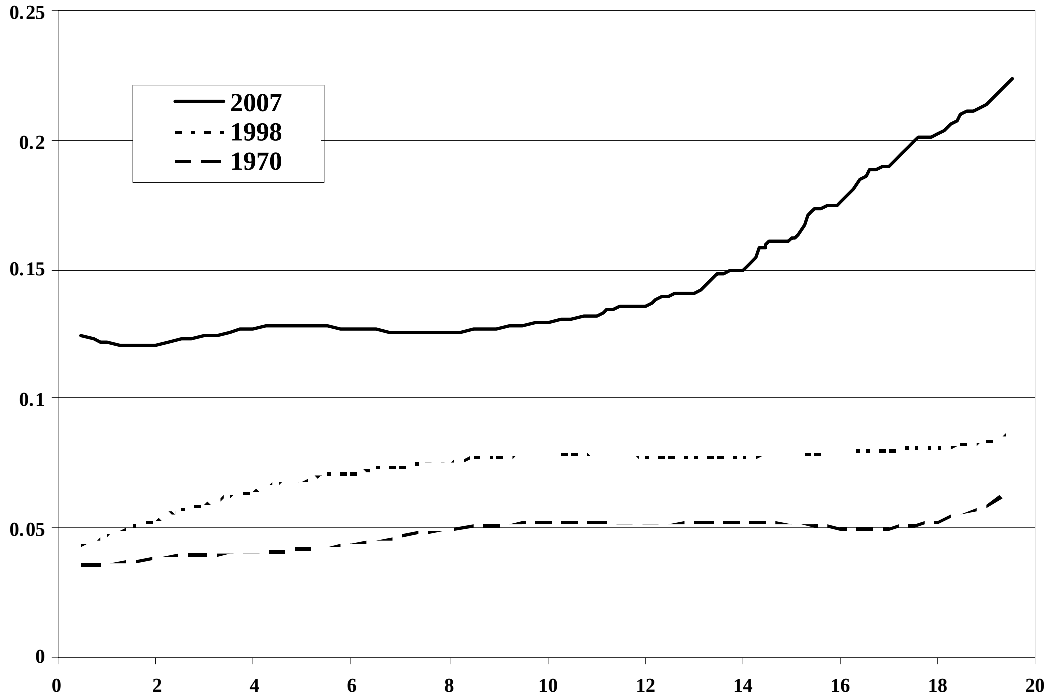

Figure 2. Fraction of Agricultural Labor Employed in Three Labor Regimes, by Landholding Size

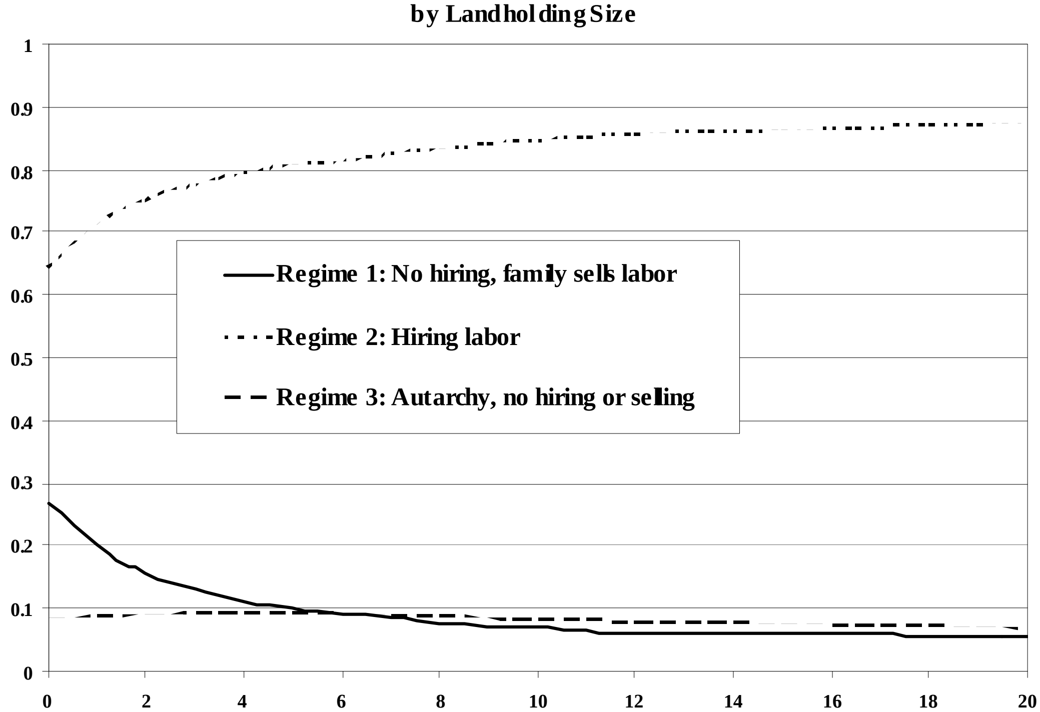

Figure 3. Measures of Per-Acre Productivity, by Owned Landholding Size (2007-8)

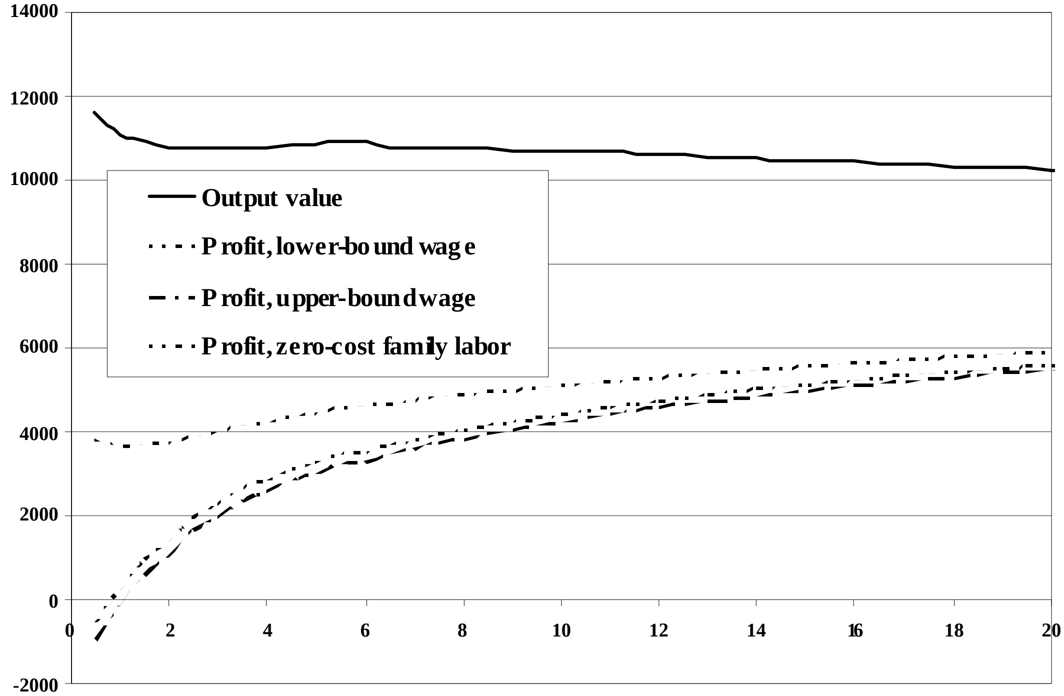

Figure 4. Locally-weighted FE-IV Estimates of the Effects of Land Owned on Profits per Acre (and one sd Confidence Bounds), by Landholding Size

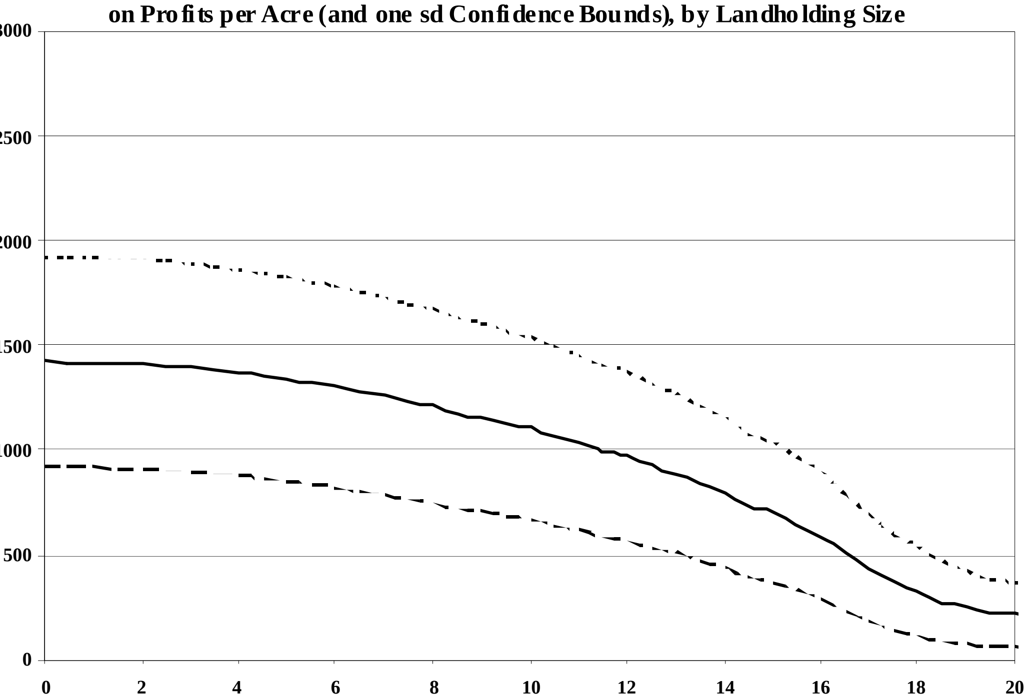

Figure 5. Estimated Reservation Rental Rate, by Owned Landholding Size

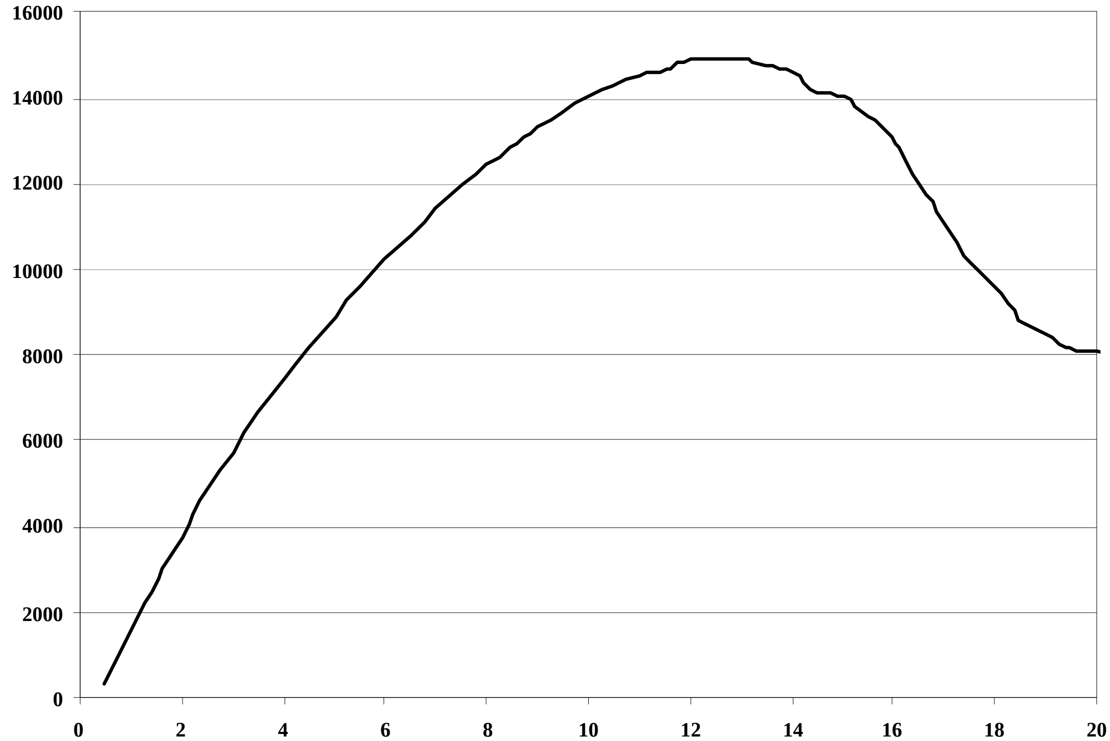

Figure 6. Within-Village Relationship Between the Probability of Leasing In and Leasing out Land, by Ownership Holdings (N=119,349)

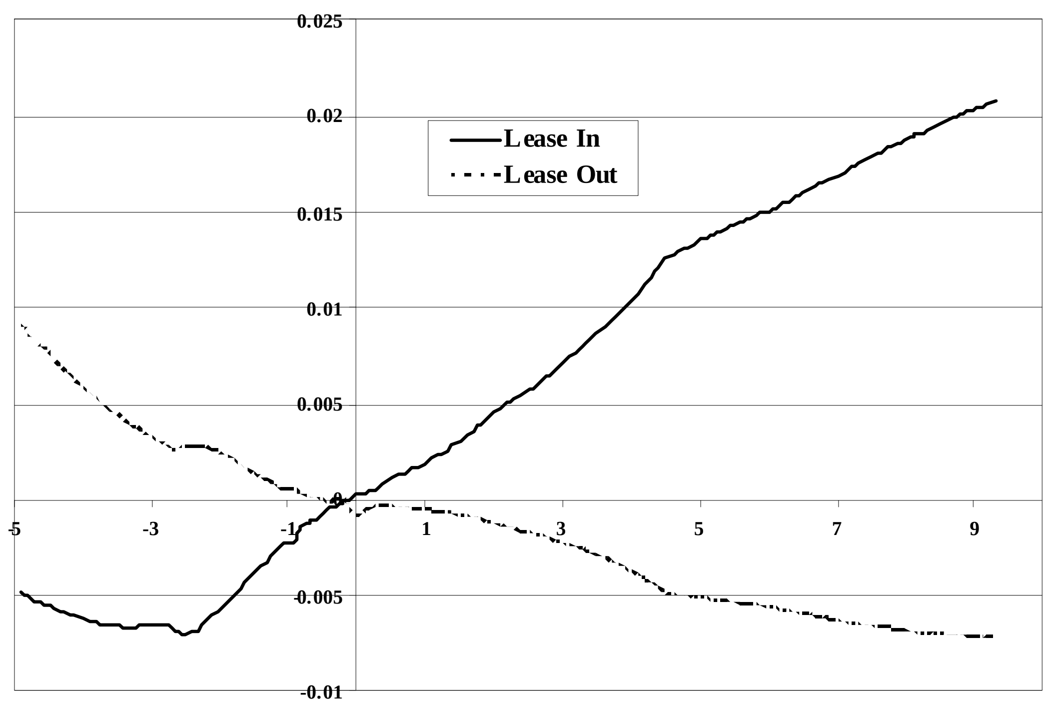

Table 1. Panel Data Estimates (1999-2008): Effects of the Use of Hired and Family Labor on Supervision Time (Adjusted Mandays), by Estimation Procedure

Estimation procedure:	OLS	Farmer Fixed-Effects[a]	Farmer Fixed-Effects-IV
Hired labor mandays, adjusted for sex/age	.0906 (2.62)	.0977 (3.39)	.573 (2.81)
Family labor mandays, adjusted for sex/age	.170 (2.96)	.0844 (2.41)	.138 (2.10)
Test statistic, H_0: supervision costs= $\chi^2(1)$, *p*-value	0.89 (.345)	0.02 (.812)	3.76 (.0525)
Number of observations	3,280	3,280	3,280
Number of farmers	1,640	1,640	1,640
Kleinberger-Paap underidentification test statistic χ^2(df), *p*-value			(7) 18.6, .0095
Hansen J overidentification test statistic χ^2(df), *p*-value			(6) 7.41, .285

Absolute value of asymptotic t-ratios in parentheses. [a]Specification includes state dummy variables and whether old person in the household aged 60+. Identifying variables include number of head's brothers, head's father's age, whether the head's father co-resided, the number of boys and the number of girls aged<10 and over 5, the number of boys and the number of girls aged>=10 and <15, and household size in 1999; and total inherited land by 1999.

Table 2. Panel Data Estimates (1999-2008):
Effects of Own Landholdings and Own Farm Equipment on Profits per Acre (Supervision Costs-adjusted), by Estimation Procedure

Estimation procedure:	Village Fixed-Effects[a]			Farmer Fixed-Effects			Farmer Fixed-Effects IV[b]		
Owned landholdings	44.7 (4.47)	46.6 (4.62)	41.7 (4.02)	42.3 (1.53)	54.5 (1.91)	54.6 (1.91)	577.8 (3.15)	653.1 (2.79)	712.8 (2.63)
Fraction of owned landholdings irrigated	-	957.8 (3.64)	936.2 (3.55)	-	1225.5 (3.11	1222.9 (3.10)	-	4254.8 (2.52)	4404.2 (2.25)
Value of farm equipment	-	-	.00290 (2.05)	-	-	.000067 (0.16)	-	-	.0189 (1.39)
Number of observations	3,967	3,967	3,967	3,967	3,967	3,967	3,524	3,524	3,524
Number of farmers	2,221	2,221	2,221	2,221	2,221	1,749	1,745	1,654	1,654
Kleinberger-Paap underidentification test statistic χ^2(df), *p*-value							(5) 11.8, .0372	(8) 19.5, .0122	(8) 15.1, .0575
Hansen J overidentification test statistic χ^2(df), *p*-value							(4) 0.63, .960	(7) 6.76, .455	(7) 10.3, .174

Absolute value of asymptotic t-ratios in parentheses. [a]Specification includes year=2008 dummy; clustered t-ratios at the household level. [b]Instruments include land inherited after 1999, assets inherited after 1999, whether the current head has brothers, the standard deviation of the schooling of inheritance claimants, the father's age in 1999, whether the father is co-resident in 1999, owned asset values in 1999, inherited irrigation assets in 1999.

Table 3. Retrospective Panel Data Estimates (2008):
Effects of Own Landholdings and Own Farm Equipment on Investment in Farm Equipment and Equipment Rental, by Estimation Procedure

Dependent variable	Equipment Investment		Equipment Hire Expenditure	
Estimation procedure	FE-Farmer[a]	FE-Farmer IV[b]	FE-Farmer	FE-Farmer IV[b]
Owned landholdings	23.4 (0.08)	916.9 (2.13)	125.5 (1.94)	185.6 (2.55)
Value of owned farm equipment	-.0874 (1.61)	-.740 (4.49)	-.0187 (4.36)	-.0326 (1.67)
Bank within 10 Km	3267 (3.05)	4187.9 (2.68)	-328.1 (1.67)	-328.6 (1.66)
Number of farmers	2,570	2,570	1,822	1,822
Kleinberger-Paap underidentification test statistic χ^2(df), *p*-value		(6) 17.2, .0085		(6) 12.8, .0464
Hansen J overidentification test statistic χ^2(df), *p*-value		(5) 4.64, .461		(5) 2.08, .838

Absolute value of asymptotic t-ratios in parentheses. [a]Specification includes year=2008 dummy; clustered t-ratios at the village level. [b]Instruments include land inherited after 1999, assets inherited after 1999, whether the current head has brothers, the standard deviation of the schooling of inheritance claimants, the father's age in 1999, whether the father is co-resident in 1999, owned asset values in 1999, and the presence of a bank within 10 km in 1999.

Table 4. Within-Farmer/Season Plot-Level Estimates (2007-8):
Effects of Plot Size on Plot-Specific Profits and Labor Costs and Use of Tractor Services

	Profits per Acre			Total Labor Costs per Acre			Any Tractor Services Used[b]		
Plot area	536.3 (4.55)	534.9 (4.54)	494.8 (4.20)	-610.5 (5.49)	-615.2 (5.50)	-568.4 (5.21)	.303 (2.01)	.317 (1.93)	.286 (1.85)
Whether plot irrigated	1564.6 (2.93)	1514.7 (2.84)	1527.1 (2.78)	-105.9 (0.17)	-151.9 (0.27)	-26.2 (0.04)	.962 (2.29)	1.01 (2.25)	1.01 (2.18)
Formal equipment rental market in village*area	-	-	713.5 (1.73)	-	-	-770.4 (2.09)	-	-	.0662 (0.14)
Include soil characteristics?[a]	N	Y	Y	N	Y	Y	N	Y	Y
Number of plot observations	16,544	16,544	16,544	16,544	16,544	16,544	16,544	16,544	16,544
Number of farmers	7,845	7,845	7,845	7,845	7,845	7,845	7,845	7,845	7,845

Absolute value of asymptotic t-ratios in parentheses clustered at the village level. [a]Soil characteristics include depth, salinity, percolation and drainage; five soil colors (red, black, grey, yellow, brown, off-white); five soil types (gravel, sandy, loam, clay, and hard clay). [b]ML conditional logit estimates.

Table 5. Within-Plot Estimates Across Three Seasons (2007-8):
Effects of Previous-Period *Farm-Level* Profit Shocks on *Plot-Level* Current Profits per Acre, by Owned Landholding Size

Farm size:	Owned Landholdings<4	Owned Landholdings>=4, <10	Owned Landholdings>=10
Farm profits per acre, all other plots, previous season	.0848 (2.10)	.112 (1.45)	-.0426 (0.62)
Farm profits per acre, this plot, previous season	-.479 (8.25)	-.549 (5.01)	-.540 (3.01)
Fertilizer use, this plot, previous season (value per acre)	1.14 (2.15)	.777 (2.11)	.363 (2.72)
Number of plot observations	5,802	3,060	1,964
Number of farmers	3,595	1,967	1,234

Absolute value of asymptotic t-ratios in parentheses clustered at the farm level. Specifications include season*village dummy variables.

Not for Publication

Appendix A.

Labor shadow prices by regime and stage

The Lagrangian incorporating the budget constraint, time constraint, and non-negativity constraints on hired and off-farm work is

$$\mathcal{L} = u(x, l_{z1}, l_{z2}) + \lambda(ag(f, e_1^*, e_2^*) - x - p_f af^*$$

(A1) $$+\sum_i (w_i(l_{oi} - al_{hi}^*) + p_{ki} aq_i^{\ v} k_i^*)) + \sum_i \mu_i (l - l_{zi} - l_{oi} - al_{fi}^* - s_f al_{fi}^* - s_h al_{hi}^*)$$

$$+\sum_i (\phi_{hi} al_{hi}^* + \phi_{oi} l_{oi})$$

First order conditions with respect to l_{io}^*, l_{if}^*, l_{ih}^*, c and l_{zi} are, respectively,

(A2) $\lambda w_i - \mu_i - \phi_{oi} = 0$

(A3) $\lambda a g_{ei} e_{il} - \mu a(1 - s_f) = 0$

(A4) $\lambda(a g_{ei} e_{il} - w_i a) - \mu s_h a + \phi_{hi} a = 0$

(A5) $u_c - \lambda = 0$

and

(A6) $u_{lzi} - \mu = 0$.

The complementary slackness conditions for the inequality constraints are

(A7) $\phi_{oi} l_{oi} = 0$

(A8) $\phi_{hi} a l_{ih}^* = 0$

Solving (A1), (A2), and (A3) yields

(A9) $g_{ei} e_{il} = \dfrac{1 + s_f}{1 - h_i^*(s_h - s_f)} w_i$,

where

(A10) $h_i^* = \phi_{oi} / (\phi_{oi} + \phi_{hi})$

We can now define three regimes. In regime (1), $l_{oi} > 0$ so applying (A7), $\phi_{oi} = 0$ and so

$h_i{*} = 0$. Thus

(A11) $g_{ei}e_{il} = (1+s_f)w_i$

In regime (2), $l_{hi} > 0$ applying (A8), $\phi_{hi} = 0$ and so $h_i{*} = 1$. Thus

(A12) $g_{ei}e_{il} = \dfrac{1+s_f}{1-s_h+s_f)}w_i$.

In regime (3), $l_{hi} = l_{oi} = 0$, and applying (A2)-(A6)

(A13) $h_i{*} = (1-u_c / u_{lzi}w_i)/(s_h - s_f)$.

Appendix B

The reservation rental price

The reservation rental price (RRP) v is the rental price per acre of land at which a farmer with a given level of land ownership and labor endowment would be indifferent to a marginal expansion of operational holdings. Note that given the potential returns to scale this need not be a global maximum. To calculate this rate incorporate a land cost va into the budget constraint in (A1):

$$\begin{aligned}\mathcal{L}' &= u(x,l_z) + \lambda(ag(f,e_1^*,e_2^*) - x - va - p_f af^* \\ &+\sum_i (w_i(l_{oi} - al_{hi}^*) - p_{ki}aq_i^{\ v}k_i^*)) + \sum_i \mu_i(l - l_{zi} - l_{oi} - al_{fi}^* - s_f al_{fi}^* - s_h al_{hi}^*) \\ &+\sum_i (\phi_{hi}al_h^* + \phi_{oi}l_o)\end{aligned} \tag{B1}$$

Differentiating with respect to a yields

$$\begin{aligned}\frac{d\mathcal{L}'}{da} &= \lambda(g(f,e_1^*,e_2^*) - v - p_f f^* + \sum_i (g_{ei}e_{ia}^* - wl_{hi}^* - p_{ki}q_i^{\ v}k_i^*)) \\ &-\sum_i \mu_i(l_{fi}^* + s_f l_{fi}^* + s_h l_{hi}^*) \\ &+\sum_i \phi_{hi}l_h^*\end{aligned} \tag{B2}$$

Setting to zero, solving for v and substituting (A2), (A3), (A4) and (A5) yields

$$\begin{aligned}v &= g(f,e_1^*,e_2^*) - p_f f^* \\ &+\sum_i (g_{ei}e_{ia}^* - \frac{1+s_f}{1-h_i^*(s_h - s_f)} w_i(l_{hi}^* + l_{fi}^*) - p_{ki}q_i^{\ v}k_i^*)\end{aligned} \tag{B3}$$

Define per acre profits as the maximum, for given h_i^*, of

$$\pi^*(a) = g(f,e_1^*,e_2^*) - p_f f^* - \sum_i \frac{1+s_f}{1-h_i^*(s_h - s_f)} w_i(l_{hi}^* + l_{fi}^*) + p_{ki}q_i^{\ v}k_i^* \tag{B4}$$

Then

$$\left.\frac{d\pi^*}{da}\right|_{h_i^*\forall i} = \sum_i g_{ei}e_{ia} \tag{B5}$$

and

$$\text{(B6)} \qquad v = \pi^*(a) + \left.\frac{d\pi^*(a)}{da}\right|_{h_i^*}$$

as first-order conditions for (B1) also satisfy those associated with maximization of (B4) with respect to machinery, fertilizer, and labor.

Appendix C

Technical scale effects on per-acre profits and inputs

The solution to the cost minimization problem in stage *i* as

(C1) $$\tilde{c}_i(e_i^*, a) = c_i(a)e_i^*$$

and the conditional factor demands as, for example,

(C2) $$\tilde{l}_i(e_i^*, a) = l_i^c(a)e_i^*$$

Implicit differentiation yields

(C3) $$\frac{dl_i^c}{da} = -\frac{\omega_k l_i^c k_i^{c\delta} \phi^{2\delta} \kappa_1^{\ \delta}}{(1-\delta)}((2-\nu)\frac{\phi_{ia}}{\phi_i} + \frac{w_{ia}^R}{w_i^r}) ,$$

where $\kappa_1 = (1-\nu)/(2-\nu)^2$. Labor used in the production of one unit of effort declines with area in the off-farm and hired-labor regimes as a result of the suitability of high-capacity machinery on larger-scale plots ($\phi_{ia} > 0$). The effect is strengthened in the autarchic regime if the effective price of labor is increasing in area among farmers in the autarchic regime ($w_{ia}^R > 0$). This latter result will obtain as long as the income effect associated with the demand for the home-produced good l_{zi} is sufficiently large relative to the substitution effect, that there is decline in family labor *per acre* as acreage expands within the autarchic regime. We assume subsequently that this condition holds.

The effect of an increase in acreage on number of machines used per unit of work is not determined. The fact that labor costs rise with area due to hiring-in results in increased machine use but since the capacity of machines rises with acreage the number of machines may either rise or fall depending on the elasticity of substitution of capital for labor. If labor and machines are sufficiently good substitutes (δ close to 1) then the number of machines will rise in the off-farm and hired-labor regimes.

(C4) $$\frac{dk_i^c}{da} = \frac{k_i^c}{1-\delta}[(\omega_l l^{c\delta}\left(2-\nu\right) - 2(1-\delta))\frac{\phi_{ia}}{\phi_i} + \omega_l l_i^{c\delta}\ \frac{\mathrm{w}_{ia}^R}{w_i^r}]$$

This result also holds both in the autarchic regime if the effective wage is increasing in area. The rising labor costs in this regime further encourage substitution towards machinery

Overall the cost per unit area is

$$\text{(C5)} \qquad \frac{dc_i}{da} = c_{ia} = -(c - w_i^R l_i^c)\frac{\phi_{ia}}{\phi_i}(2-\nu) + w_{ia}^R l^c \ ,$$

This expression is negative, except possibly in the autarchic regime. In the autarchic regime the effective wage rises with land area leading to higher labor costs that may fully or partially offset any benefits from increased machine capacity.

To actually determine how much work is done and the total use of labor and machinery we now return the per-acre profit-maximizing equation (14), which can now be written

$$\text{(C6)} \qquad \pi^*(a) = \max g(f^*, e_1^*, e_2^*) - p_f f^* - \sum_i c_i(a) \cdot e_i^*$$

The envelope condition implies

$$\text{(C7)} \qquad \frac{d\pi^*}{da} = -\sum_i c_{ia} e_i^*$$

which is positive except possibly when the autarchic regime prevails in one or more stages. Because profitability per acre may decline with acreage during the autarchic stage due to the rise in the effective wage and because as acreage increases a farm will in general transition from off-farm to autarchy to hired labor, overall profitability per acre may be lower in larger farms (in regime 2) than smaller farms (in regime 1).

Because we assume work is complementary across stages, work per unit area will increase in area

$$\text{(C8)} \qquad \frac{de_j{}^*}{da} = \sum_i \varepsilon_{e_j c_i} \frac{e_j{}^*}{c_i} c_{ia} \ .$$

where $\varepsilon_{e_j c_i}$ is the elasticity of demand for work in stage *j* with respect to the price in stage *i* and so forth. Fertilizer per unit area increases in area

$$\text{(C9)} \qquad \frac{df^*}{da} = \sum_i \varepsilon_{fc_i} \frac{f^*}{c_i} c_{ia}$$

because fertilizer and work are assumed to be complementary.

The number of machines k per unit area will be increasing in area, for δ sufficiently close to 1 because overall work increases and the number of machines per unit work increases. In particular,

$$\text{(C10)} \quad \frac{dk_i*}{da} = k_i^c \frac{de_i*}{da} + e_i*\frac{dk_i^c}{da}$$

Using (C10), (C8) , (C5) and (C4) it follows that whether total expenditures on machinery will rise for $\delta < 1$ as land size increases depends on whether the pricing of machinery is sufficiently elastic to capacity. Regardless, as is evident from (16) with $\phi_{ia} > 0$, machine capacity (and thus the probability that a machine of a given capacity is used in a given stage), is increasing in area.

An analogous expression holds for labor.

$$\text{(C11)} \quad \frac{dl_i*}{da} = l_i^c \frac{de_i*}{da} + e_i*\frac{dl_i^c}{da}$$

The effect of an expansion in area on the amount of manual labor used per acre is also ambiguous. Equation (C3) shows that in regimes (1) and (2) there is a decrease in labor per unit of effort associated with machinery but this is offset by an increase in total work (C8) and (C5). Thus if the demand for work is price inelastic or labor and machines are sufficiently good substitutes an increase in area will result in less work within these two regimes. In the autarchic regime there are two additional effects: the cost of work may rise with area (C5) thus leading to less overall work and the rising effective cost of labor will lead to less labor per unit of effort (C3). Both effects lead to less labor per unit area as acreage increases. Thus if the demand for work is price inelastic or labor and machines are sufficiently good substitutes an increase in area will result in less work overall.

Appendix D

Testing for perfect capital markets using measured profits that ignore interest costs

The profit function in terms of profits that do not include interest costs (estimated profits) is given by

(D1) $$\hat{\pi}^* = g(e^*, f^*) - c(a)e^* - p_f f^*,$$

where the inputs are determined by programming problem (19). In this case we have

(D2) $$\frac{d\hat{\pi}^*}{da} = (\rho_b - 1)(c(a)\frac{de^*}{da} + p_f \frac{df^*}{da}) - c'(a)e^*$$

where $\rho_b > 1$ and the second term in parentheses is positive. Estimated profits also increase with owned landholdings. Comparing (D2) to (20) indicates that the gradient in estimated profits, as with that of true profits, is steeper than would be the case in the absence of credit market effects (C7). In the case in which there are no technical scale economies associated with machinery or supervision costs so $c'(a) = 0$, (C7) would be zero but (20) would be positive if $\rho_a < 0$ and (D2) would be positive if $\rho_{ab} < 0$ so that work and input use per acre expands in area.[1]

A direct test of credit market constraints can be obtained by examining the returns to owned capital assets using true or estimated profits. The marginal return to capital in terms of true profits is given by

(D3) $$\frac{d\pi^*}{do^*} = -\rho_b + (1 + r_0) = r(a, b^*) - r_0 + \frac{dr(a, b^*)}{db^*} b^* > 0,$$

while the marginal return to estimated profits is

(D4) $$\frac{d\hat{\pi}^*}{do^*} = (\rho_b - 1)(c(a)\frac{de^*}{do^*} + p_f \frac{df^*}{do^*}).$$

The observed marginal returns to capital assets in the presence of credit constraints evidently

[1]These conditions coincide in the case in which the interest rate is proportional to borrowing per acre.

differ depending on how profits are computed. However, it is easily established that when $r(a, b^*) = r_0$, that is when borrowing costs are independent of land ownership and equal to the returns on savings, the marginal return to capital assets is zero for either measure of profits. This is because variation in owned machinery at the margin has no effects on the use of production inputs,

$$\text{(D5)} \qquad \frac{de^*}{do^*} = \frac{df^*}{do^*} = 0 \ .$$

Therefore, the finding that there is a non-zero return, in terms of estimated profits, to owned capital assets would reject the hypothesis of perfect capital markets.

Appendix E

Farm Size and Profit Dynamics

Addressing profit dynamics in a forward-looking model is complicated and thus we illustrate the basic structure using a simplified production function with one variable input, fertilizer, and assume that the production function and the cost of borrowing are quadratic in their respective arguments. In this model, farmers adjust their end-of-season savings based on unanticipated income shocks and subsequently use this savings to finance fertilizer purchases. We assume a stationary problem with state variables representing soil nutrition n^* and cash on hand h^*. Fertilizer levels are chosen prior to the realization of a shock θ_t. We define the value function recursively as follows:

(E1) $v(n_t^*, h_t^*) = \max E_t\,(\theta_t + g(f_t^* + n_t^*) - r(f_t^* - h_t^*) - h_{t+1}^* + \beta v(n_{t+1}^*, h^*_{t+1}))$,

where β is the discount factor and

(E2) $$h_{t+1}^* = h_t^* + \lambda\,(\theta_t - E_t\theta_t)\,,$$

where λ denotes the extent to which unanticipated shocks are saved. For $\lambda = 1$ unanticipated shocks are fully saved as in the permanent income hypothesis and for $\lambda = 0$ cash on hand is just a constant. Soil nutrients depend positively on both the previous period's stock of nutrients and fertilizer use and negatively on the output shock θ_t,

(E3) $$n_{t+1}^* = n_t^* + f_t^* - \alpha\theta_t$$

The idea is that more rapidly growing plants, for example, will deplete the soil of nutrients relatively quickly. For example, if θ_t is rainfall, more nutrients are used if rainfall and soil nutrients are complements. The production and credit functions are

(E4) $$g(x) = g_1 x - g_2 x^2$$

and

(E5) $$r(x) = x + r_2 x^2\,,$$

where x are the respective arguments in (E1) and for notational simplicity we set the fertilizer price to one. All of the parameters in (E4) and (E5) are positive; that is we assume that production is characterized by diminishing returns but the cost of credit r increases at a higher rate with the amount of credit.

Estimated profits in this model (again, profits that do not account for borrowing costs are):

(E6) $$\hat{\pi}_1{}^* = \theta_1 + g(f_1{}^* + n_1{}^*) - f_1{}^*$$

Farmers optimally choose their level of savings and use of fertilizer. Given the soil dynamics and savings behavior, the effect of a previous period shock on next-period's profits is thus

(E7) $$\frac{d\pi_1{}^*}{d\theta_0} = -\alpha \frac{g_2 + g_1 r_2 - \beta v_{nn}}{g_2 + r_2 - \beta v_{nn}} + \lambda \frac{(1-\beta)(g_1 - 1)r_2}{g_2 + (1+\beta)r_2 - \beta v_{nn}},$$

where v_{nn} is the second derivative from the value function, with $v_{nn} < g_2 + r_2$ and $g_1 < 1$ for an interior maximum.

The two key parameters in (E7) are α and λ, reflecting the influence of the dynamic nutrient and savings functions. If $\lambda = 0$ so that liquidity h does not depend on unanticipated income shocks the lagged profit shock only influences profits in the next period because of nutrient depletion. A positive shock in period 0 in that case leads to greater nutrient depletion and therefore reduces profitability in period 1. Conversely, if there is no nutrient carryover so that $\alpha = 0$ there is only a liquidity effect: a positive shock in period 0 induces higher savings and thus more cash on hand in the next period so that less credit is needed for fertilizer. The lower cost of borrowing increases fertilizer use and thus increase profitability in the current period. This effect vanishes if $r_2 = 0$, that is, if borrowing costs do not rise as the demand for credit increases.

Figure A1. Relationship Between Mean Hectares Harvested per Hour and Combine Weight, by Crop: Indigenous Indian Combines (Source: Singh (2006))

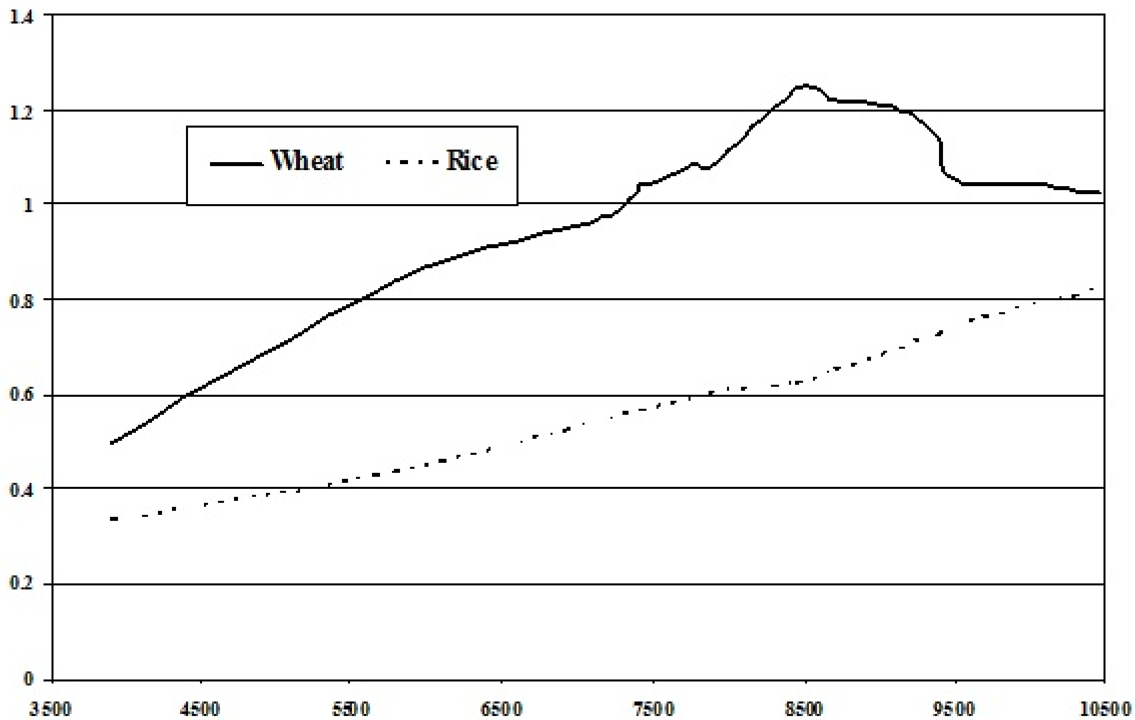

Figure A2: Illustrations of rice harvesting technologies appropriate for different operational scales

Figure A3. Cumulative Distribution of Owned Landholdings (Acres), by Data Source

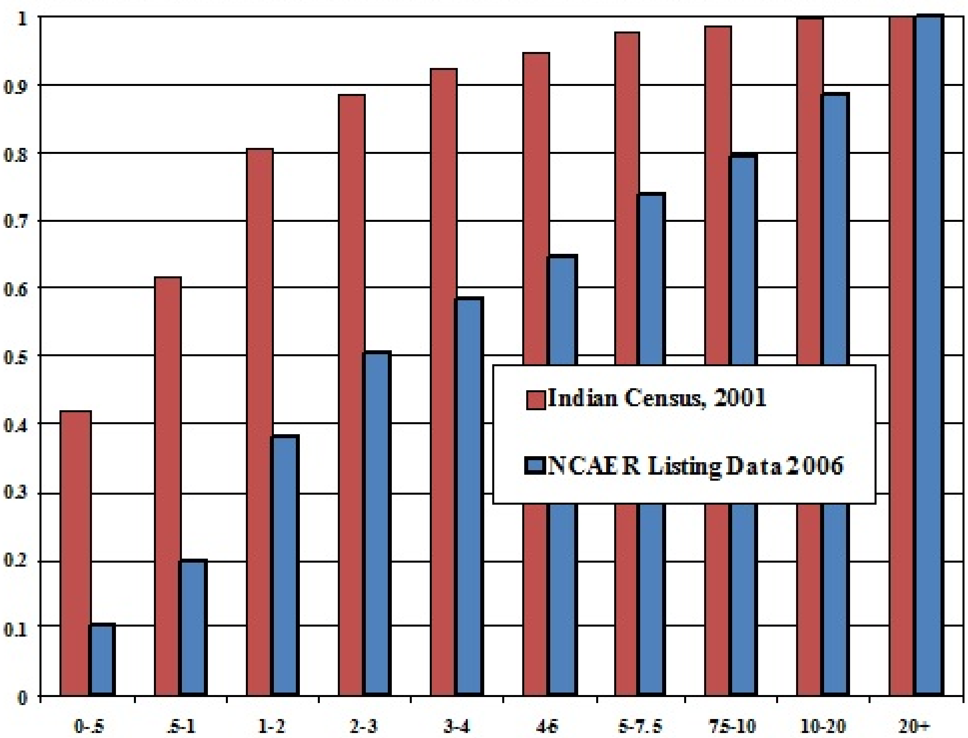

Figure A4. Total Mandays of Labor Used per Acre, Adjusted for Gender and Age, by Owned Landholding Size

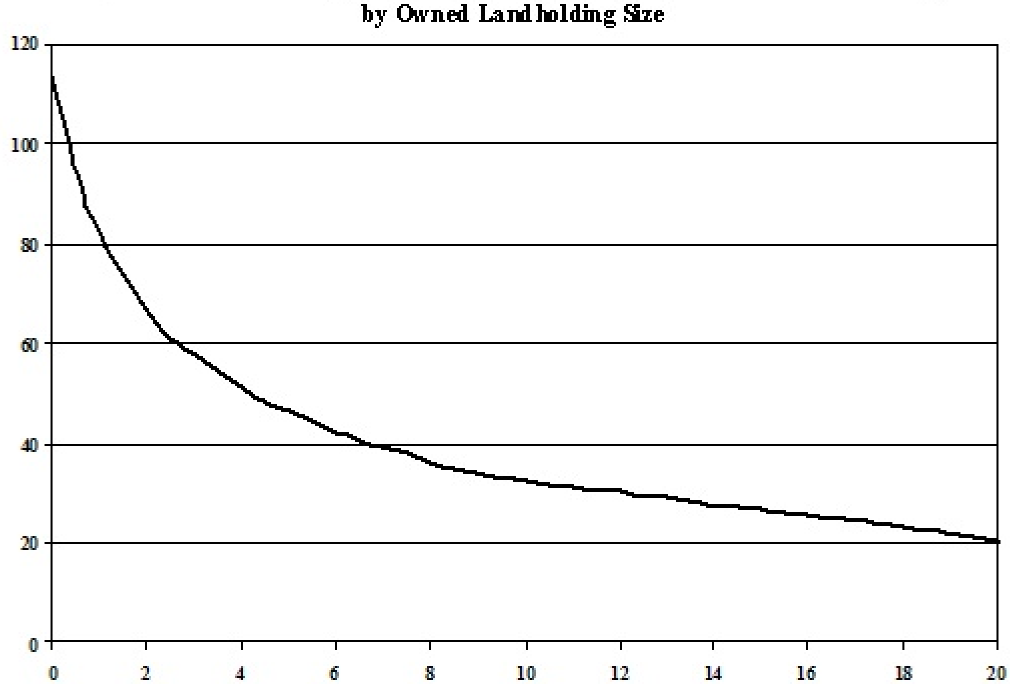

Figure A5. Locally-weighted FE-IVEstimates of the Returns to Capital Equipment Value (and one sd Confidence Bounds), by Landholding Size

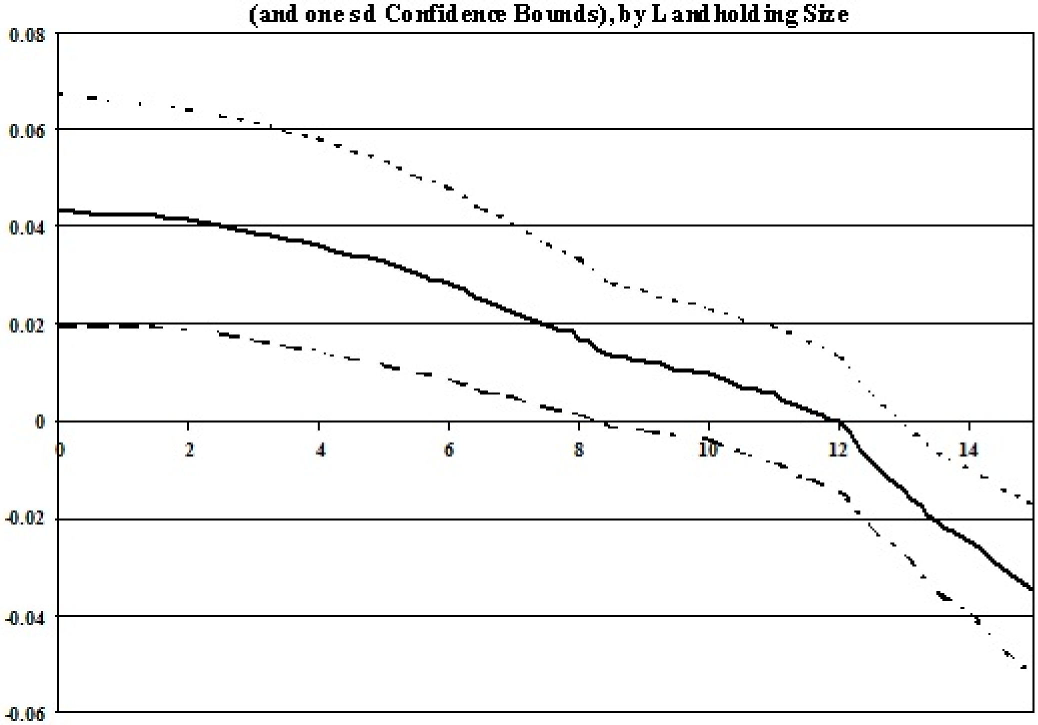

Figure A6. Within-Plot Estimates of the Effects of Prior-Season Other-Plot Profits On Current Profits per Acre (and one sd Confidence Bounds), by Owned Landholding Size

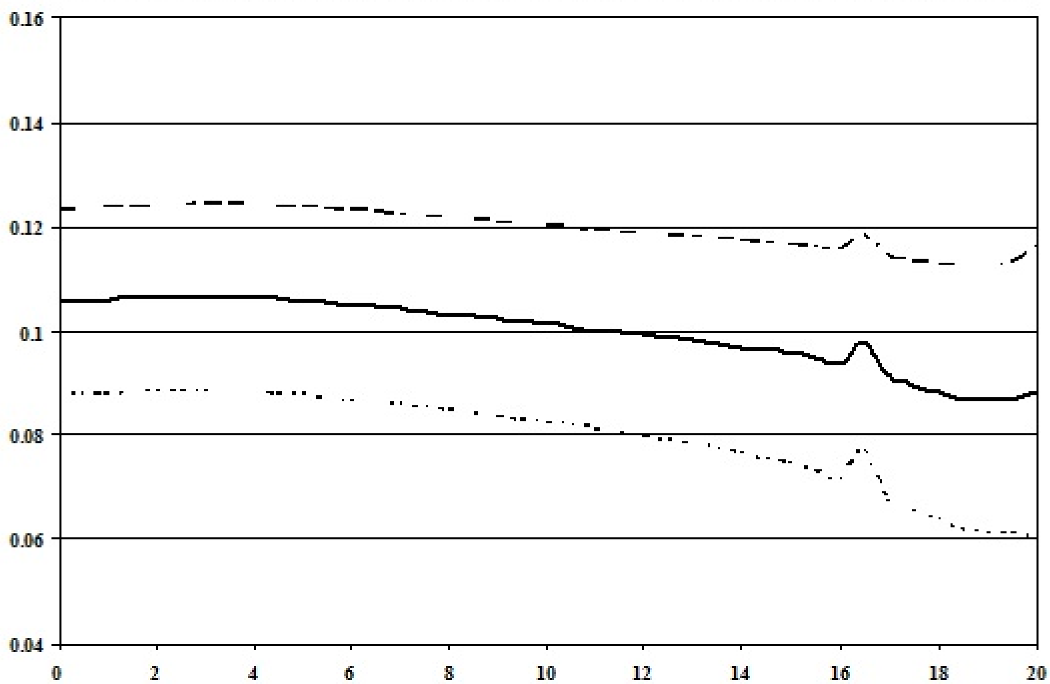

Table A1
First-Stage Estimates for Supervision Function (1999-2007/8 Panel)

	ΔHired Labor	ΔFamily Labor
Inherited land prior to 1999	-.556	-1.43
	(2.22)	(3.26)
Males aged 60+ in 1999	-5.04	-7.29
	(2.60)	(2.14)
Head's father not co-resident in 1999	-8.55	-10.1
	(2.44)	(1.65)
Head's father's age in 1999	.0194	.179
	(0.22)	(1.17)
Number of head's brothers in 1999	-3.50	7.51
	(1.24)	(1.52)
Household size in 1999	.677	-.549
	(2.14)	(0.99)
Boys aged 5-9 in 1999	-.191	20.4
	(0.09)	(5.72)
Girls aged 5-9 in 1999	-.798	-14.8
	(0.37)	(3.90)
Boys aged 10-14 in 1999	3.07	-6.96
	(1.31)	(1.70)
N	1,640	1,640
F(8, 1,614), excluded instruments [p]	2.58 [.008]	8.05 [.000]
F(25, 1,614), all regressors [p]	6.36 [.000]	8.10 [.000]
Cragg-Donald Wald statistic, underidentification, $\chi^2(7)$ [p]	20.87 [.004]	

All specifications include state dummy variables. Asymptotic t-ratios in parentheses.

Table A2
First-Stage Estimates for Profit Function (1999-2007/8 Panel)

	ΔLand	ΔFraction Irrigated	ΔFarm Equipment ($x10^{-3}$)
Inherited land between 1999 and 2007-8	.195 (4.52)	-.00032 (0.10)	1.00 (1.70)
Inherited fraction of irrigated land by 1999	.735 (2.61)	-.446 (2.35)	18.5 (4.80)
Head's father not co-resident in 1999	.688 (1.20)	.0365 (0.82)	6.19 (0.79)
Head's father's age in 1999	-.00464 (0.45)	-.00024 (0.30)	-.127 (0.90)
Number of head's brothers in 1999	.102 (0.32)	.00264 (0.11)	4.27 (0.98)
Head's brothers co-resident in 1999	-.557 (3.67)	-.00203 (0.17)	-1.64 (0.79)
Standard deviation of brothers' schooling in 1999	-.060 (1.05)	-.00107 (0.24)	2.05 (2.62)
Inherited value of mechanical assets by 1999 ($x10^{-3}$)	.00385 (0.70)	.00062 (1.44)	.0649 (0.86)
Inherited value of nonmechanical assets by 1999 ($x10^{-3}$)	-.0882 (1.99)	-.00016 (0.05)	3.55 (5.87)
Inherited assets between 1999 and 2007-8 ($x10^{-3}$)	.540 (0.54)	.0376 (0.48)	-10.7 (0.78)
N	1,374	1,374	1,374
F(10, 1,363), excluded instruments [p]	4.86 [.000]	41.9[.000]	8.05 [.000]
Cragg-Donald Wald statistic, underidentification, $\chi^2(8)$ [p]		39.42 [.000]	

Asymptotic t-ratios in parentheses.

Table A3. Farmer-Fixed-Effects IV Panel Data Estimates (1999-2008)[b]:
Effects of Own Landholdings and Own Farm Equipment on Alternative Measures of Profits per Acre

Dependent variable:	Profits per Acre per Acre (Upper-Bound Shadow Labor Cost under Autarchy)			Profits per Acre (Costless Family Labor)		
Owned landholdings	574.9 (3.13)	637.9 (2.79)	474.5 (2.24)	511.3 (2.15)	526.3 (2.85)	1506.3 (3.05)
Fraction of owned landholdings irrigated	-	3822.4 (2.27)	2924.1 (1.79)	-	2251.7 (1.49)	4974.1 (2.21)
Value of farm equipment	-	-	.0136 (1.05)	-	-	.0362 (1.84)
Number of observations	3,524	3,524	3,524	3,524	3,524	3,524
Number of farmers	1,745	1,654	1,654	1,745	1,654	1,654
Kleinberger-Paap underidentification test statistic χ^2(df), p-value	(8) 24.6 .0018	(8) 19.5 .0122	(8) 15.1 .0575	(5) 18.8, .0021	(8) 19.9, .0106	(8) 15.1, .0575
Hansen J overidentification test statistic χ^2(df), p-value	(7) 7.38 .390	(7) 7.06.6 .423	(7) 9.81 .200	(4) 2.45, .654	(7) 8.73, .273	(7) 10.3, .174

Absolute value of asymptotic t-ratios in parentheses; clustered at the village level. [b]Instruments include land inherited after 1999, assets inherited after 1999, whether the current head has brothers, the standard deviation of the schooling of inheritance claimants, the father's age in 1999, whether the father is co-resident in 1999, owned asset values in 1999, inherited irrigation assets in 1999.

Table A4
First-Stage Estimates for Equipment Investment and Machinery Rental (Retrospective 2007/8 Panel)

	ΔLand	Δ Equipment Value ($x10^{-3}$)
Inherited land between 1999 and 2007-8	.959	1.27
	(77.1)	(4.33)
Inherited assets between 1999 and 2007-8 ($x10^{-3}$)	-.00052	.573
	(0.10)	(4.89)
Head's father not co-resident in 1999	.118	1.77
	(1.14)	(0.73)
Head's father's age in 1999	-.00524	-.0715
	(1.98)	(1.14)
Number of head's brothers in 1999	.0881	1.71
	(1.02)	(0.84)
Standard deviation of brothers' schooling in 1999	.00269	1.30
	(0.18)	(3.72)
Change in proximity of bank between 1999 and 2007-8	-.158	2.60
	(1.90)	(1.32)
Bank nearby in 1999	-.149	1.63
	(1.28)	(0.59)
N	2,570	2,570
F(7, 2,561), excluded instruments [p]	863.1 [.000]	7.46[.000]
F(8, 2,561), all regressors [p]	755.3 [.000]	8.28[.000]
Cragg-Donald Wald statistic, underidentification, $\chi^2(8)$ [p]	39.77 [.000]	

Asymptotic t-ratios in parentheses.

Table A5. Within-Farmer/Season Plot-Level Estimates for Rice Plots Only (2007-8):
Effects of Plot Size on Plot-Specific Profits and Labor Costs and Use of Tractor Services

	Profits per Acre			Total Labor Costs per Acre			Any Tractor Services Used[b]		
Plot area	601.2 (3.82)	590.0 (3.71)	500.8 (3.05)	-859.1 (4.91)	-854.5 (4.89)	-777.6 (4.55)	1.10 (2.24)	2.03 (2.43)	.901 (1.50)
Whether plot irrigated	855.1 (1.36)	885.4 (1.37)	809.7 (0.98)	429.9 (0.78)	344.7 (0.62)	820.8 (1.40)	1.09 (1.39)	173 (1.72)	17.2 (9.89)
Formal equipment rental market in village*area	-	-	617.8 (1.18)	-	-	-621.5 (1.00)	-	-	.412 (0.49)
Include soil characteristics?[a]	N	Y	Y	N	Y	Y	N	Y	Y
Number of plot observations	5,184	5,184	5,184	5,184	5,184	5,184	5,184	5,184	5,184
Number of farmers	2,180	2,180	2,180	2,180	2,180	2,180	2,180	2,180	2,180

Absolute value of asymptotic t-ratios in parentheses clustered at the village level. [a]Soil characteristics include depth, salinity, percolation and drainage; five soil colors (red, black, grey, yellow, brown, off-white); five soil types (gravel, sandy, loam, clay, and hard clay). [b]ML conditional logit estimates. All specifications include plot distance to homestead.