Input Transaction Costs, Mechanization, and the Mis-allocation of Land

Andrew D. Foster and Mark R. Rosenzweig

February 2017

This research is aimed at re-assessing the role of scale in the profitability of farming.

Consensus of literature focused on low-income countries:

> There is an inverse relationship between farm (plot) size and productivity.
>
> The existence of larger farms thus represents a mis-allocation of farmland.

This conclusion seems at odds with global differences in agricultural productivity and farm scale.

Is it really plausible that there are scale dis-economies in farming? And if so, why?

Challenges to Identifying Scale Economies

1. Span of plot/land sizes limited in most low-income countries.

2. Plot size, plot quality and farmer ability may be correlated.

3. Plot size may be measured with error and that error may be correlated with plot size.

4. The land allocation process may be endogenous (see 2 above).

Challenges to Identifying *Why* there are Scale Economies

1. Need a model of input markets, farmer behavior.

2. Need information on all input costs to calculate returns on land (profits).

3. Need information on the unit prices paid per operation and quantities used by input type.

4. Need price schedules by quantity hired by input type and capacity.

5. Need information on the characteristics of equipment used: capacity (e.g, horsepower, work accomplished per time-unit or acreage).

Data We Use: ICRISAT India VLS data set

6-year panel of farmers at the plot level, 2009-2014

20 villages in 6 states

819 farmers

2,015 plots

Detailed information on input quantities and prices by type of input and outputs *by operation* and individual plot.

Accurate information: Farmers interviewed every three weeks throughout the year on all transactions.

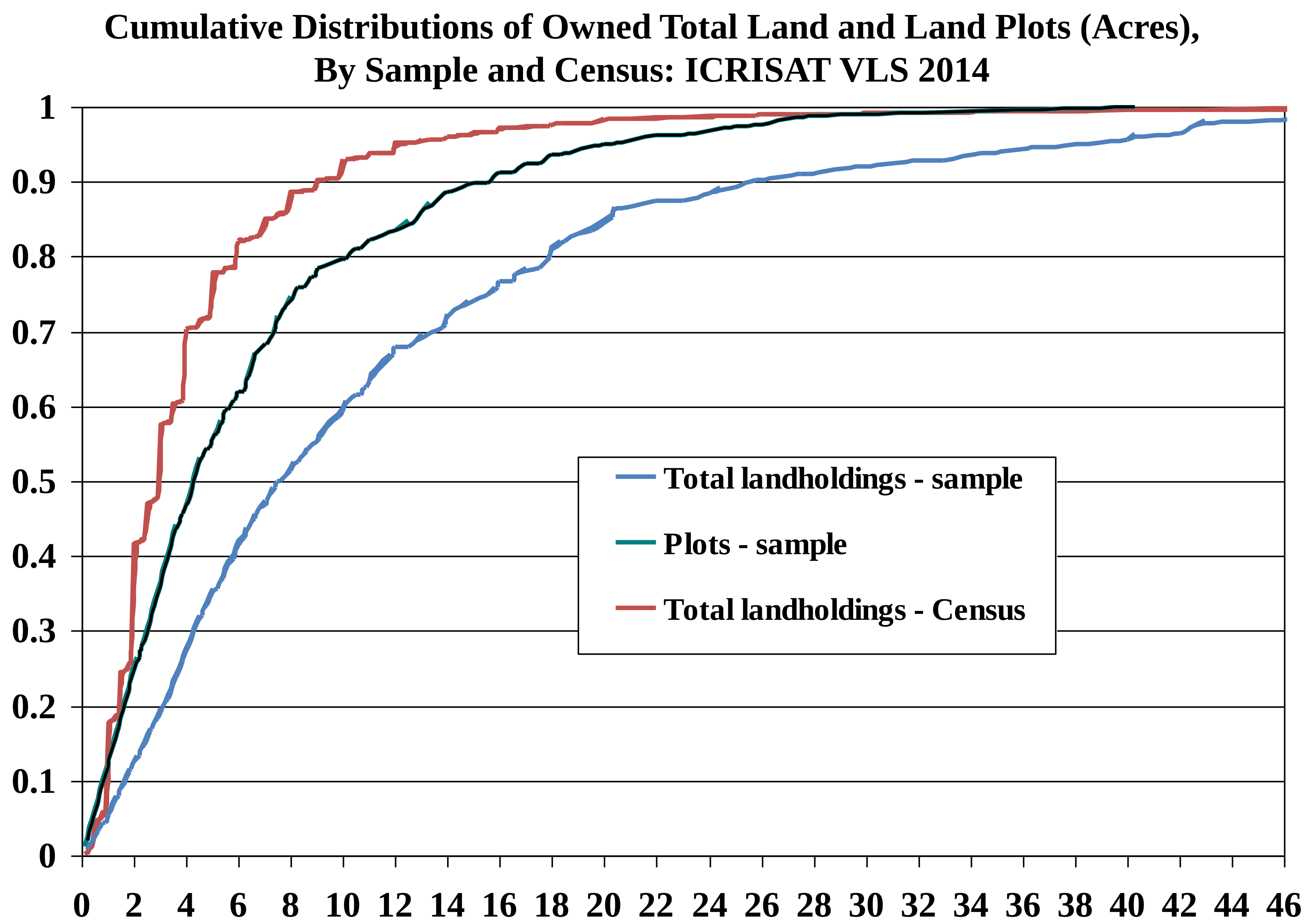
Multiple measures of plot quality and farmer capacity:

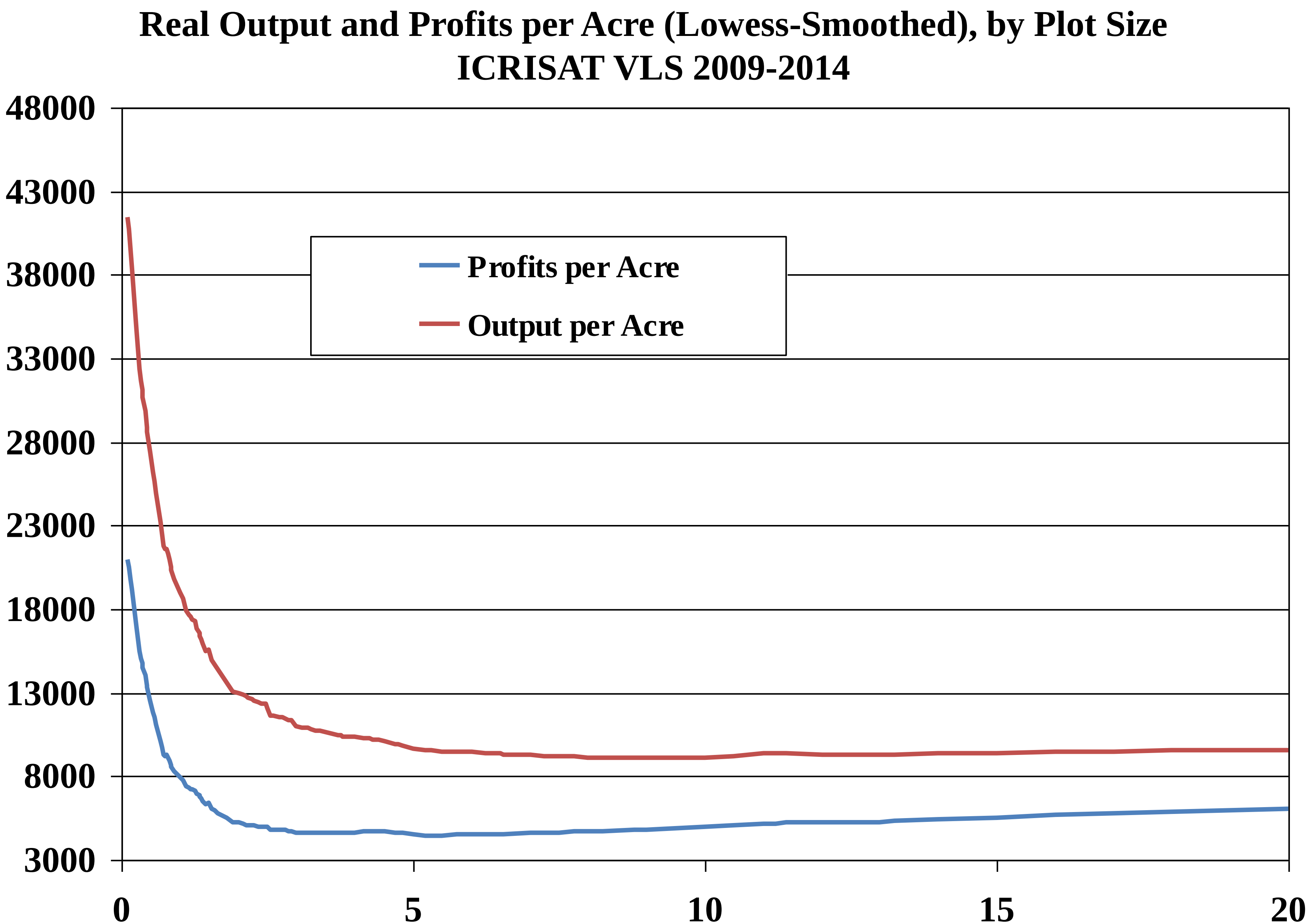
> We have for each plot: share of the plot irrigated, soil depth, distance from the residence, 12 soil type categories, 6 soil degradation levels, 4 degrees of soil fertility, 4 slope categories, farmer schooling, age, gender and wealth.

Input price schedules by quantity of work time.

Information on how plots were acquired, including inheritance date if inherited.

Complete inventories of owned assets.


Cumulative Distributions of Owned Total Land and Land Plots (Acres),
By Sample and Census: ICRISAT VLS 2014
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46
Total landholdings - sample
Plots - sample
Total landholdings - Census


Real Output and Profits per Acre (Lowess-Smoothed), by Plot Size
ICRISAT VLS 2009-2014
Profits per Acre
Output per Acre
48000
43000
38000
33000
28000
23000
18000
13000
8000
3000
0
5
10
15
20

Measurement and Endogeneity Issues

Is the relationship between average plot size and profitability per acre spurious?

Possible that smaller plots are higher quality, owned by more capable farmers: may be families equalize incomes of family members via inheritance by trading off size and land quality, so that smaller plots are more productive plots

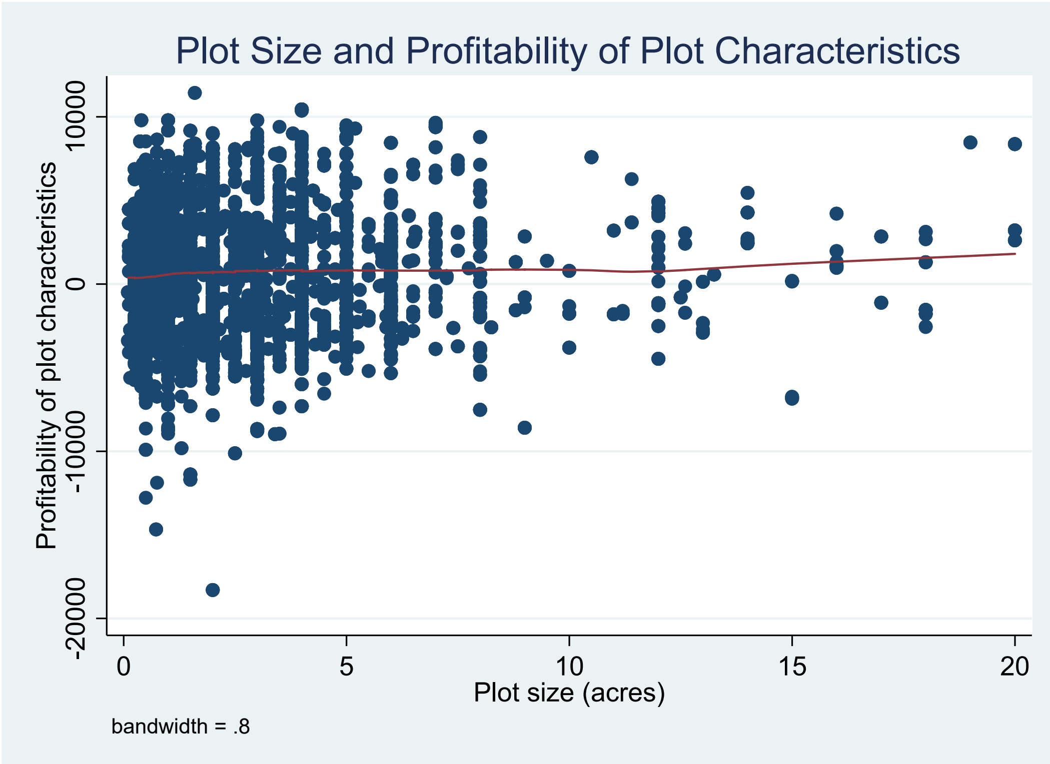
Possible that plot and farm size measured with error, and that the error is greater for larger plots (greater negative bias for larger scale).

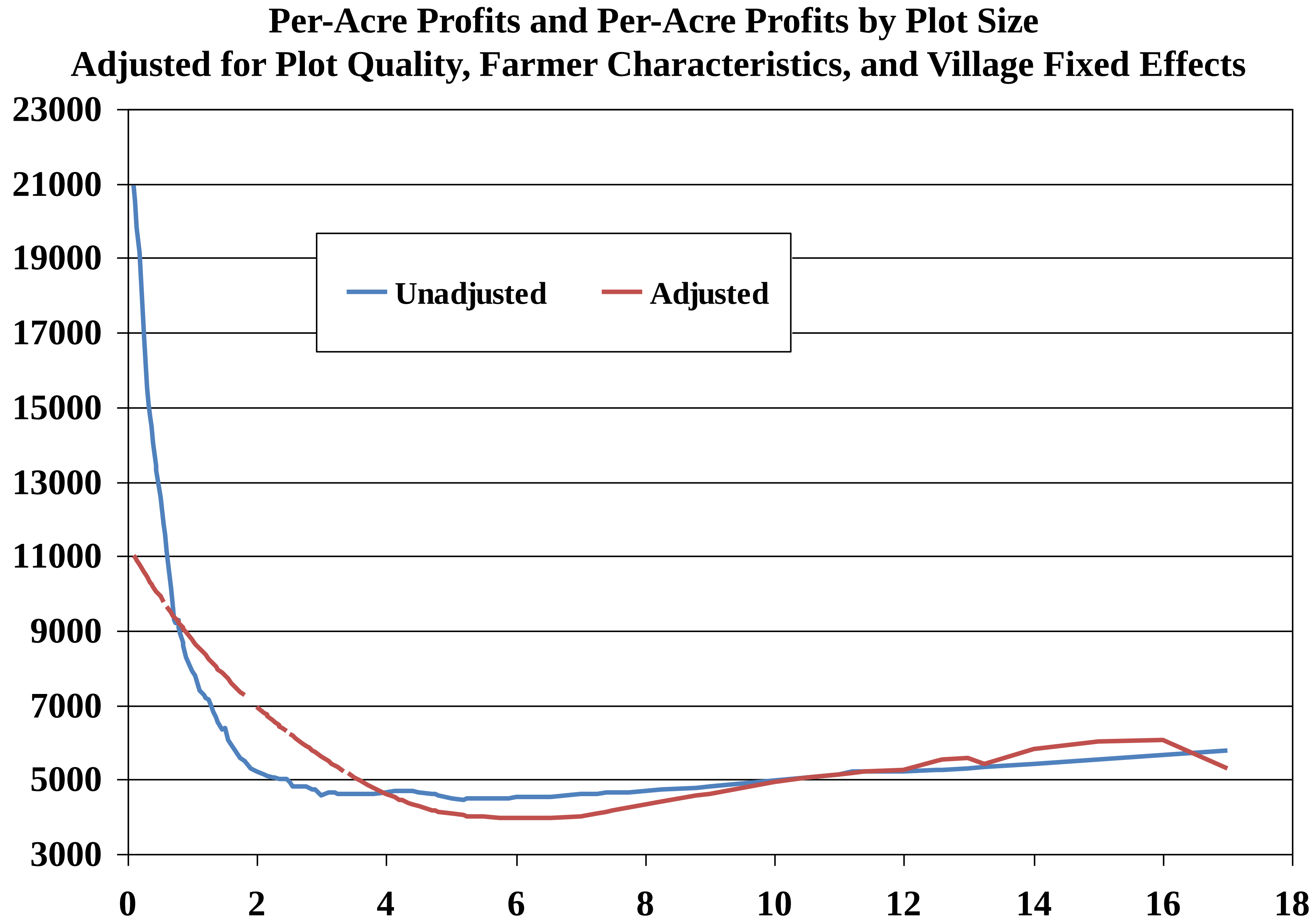
Tests using information on land inheritance, and plot characteristics.

Table 1
Does Land Quality Heterogeneity Affect Estimates of the Relationship Between Profits and Plot Size?
(All *Kharif* Seasons 2009-2014)

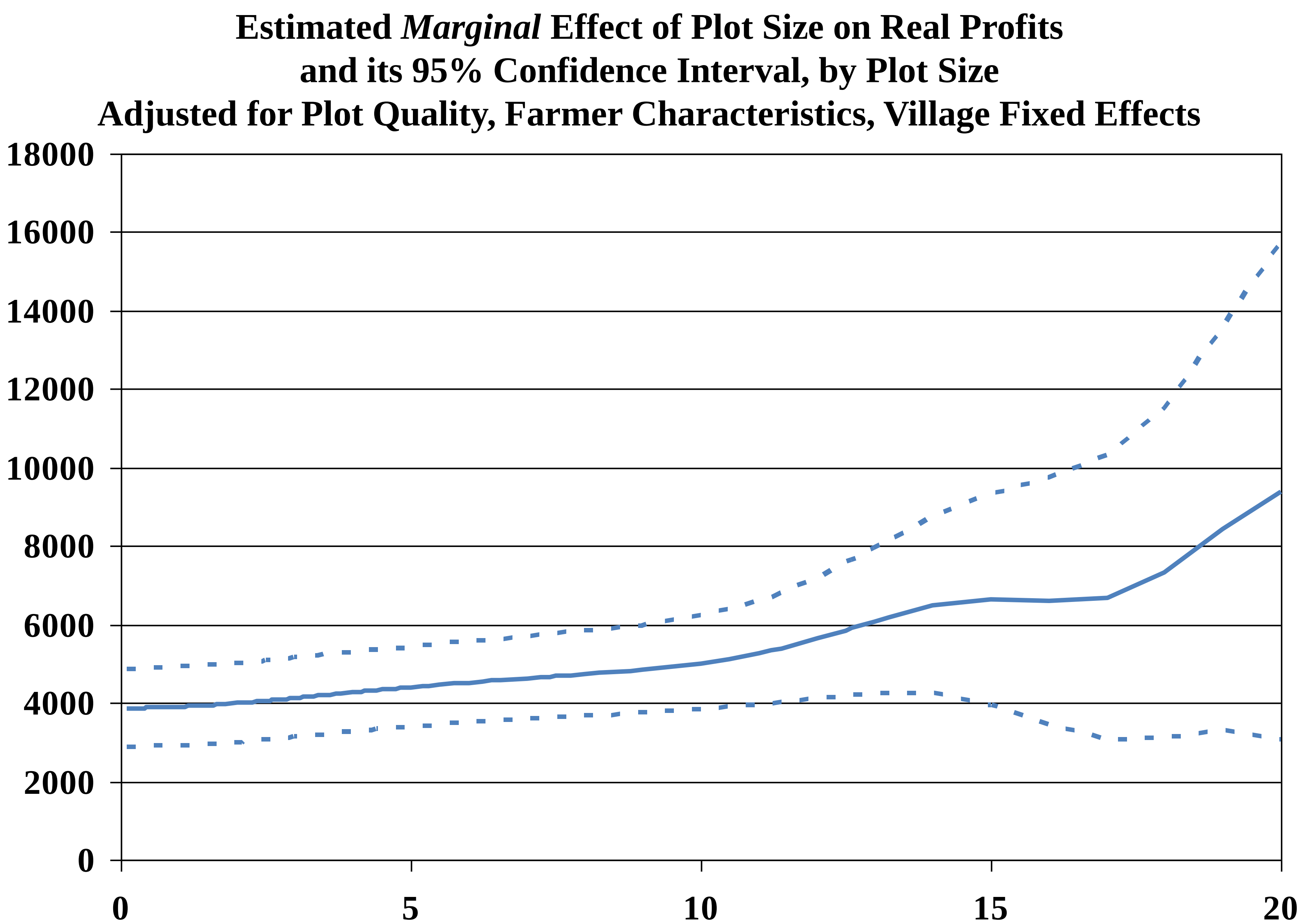
Variable	(1)	(2)	(3)	(4)
Plot size (acres)	4656.7	4766.4	4696.6	4854.8
	(584.9)	(589.4)	(591.0)	(1218.6)
Village/year FE	N	Y	Y	-
Farmer/year FE	-	-	-	Y
Plot and household characteristics	N	N	Y	-
Plot characteristics	-	-	-	Y
H_0: Plot and household characteristics = 0	-	-	6.43	-
F(25,105) [p]			[.0000]	
H_0: Plot characteristics = 0	-	-	-	1.09
F(23,105) [p]				[.3694]
Number of observations	6,777	6,777	6,777	6,777

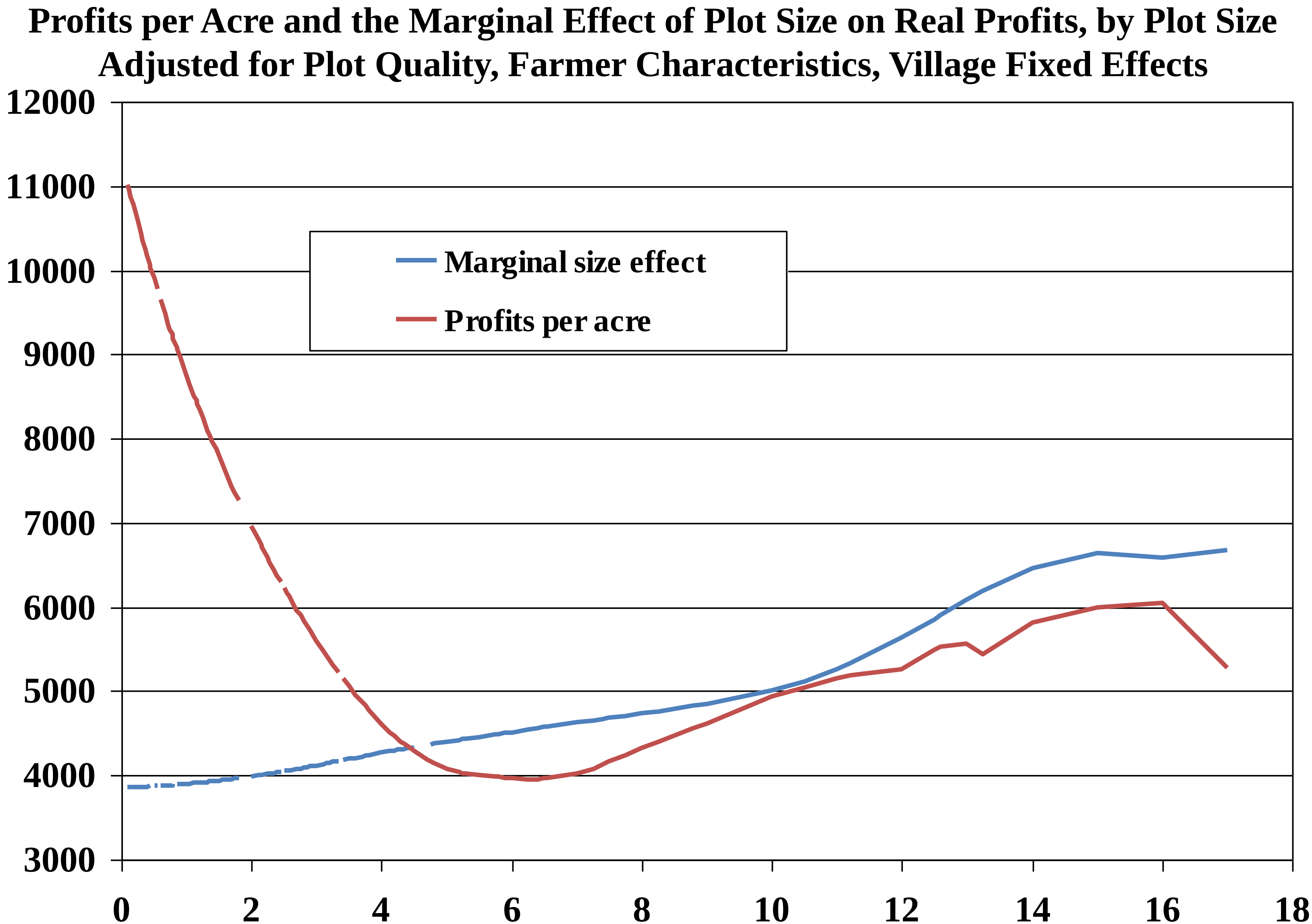
Standard errors in parentheses clustered at the village/year level.


Plot Size and Profitability of Plot Characteristics
Profitability of plot characteristics
10000
0
-10000
-20000
0
5
10
15
20
Plot size (acres)
bandwidth = .8



Per-Acre Profits and Per-Acre Profits by Plot Size
Adjusted for Plot Quality, Farmer Characteristics, and Village Fixed Effects
Unadjusted
Adjusted
23000
21000
19000
17000
15000
13000
11000
9000
7000
5000
3000
0
2
4
6
8
10
12
14
16
18


Estimated *Marginal* Effect of Plot Size on Real Profits
and its 95% Confidence Interval, by Plot Size
Adjusted for Plot Quality, Farmer Characteristics, Village Fixed Effects
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
5
10
15
20


Profits per Acre and the Marginal Effect of Plot Size on Real Profits, by Plot Size
Adjusted for Plot Quality, Farmer Characteristics, Village Fixed Effects
Marginal size effect
Profits per acre
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
0
2
4
6
8
10
12
14
16
18

Land Allocation: Turnover of Owned Land

1. Only 0.74% of all plot observations from 2009-2014 involved a purchase of land.

2. Of all acquisitions of land from 2009-2014 (5.8% of all plot observations), almost all were due to inheritance or family transfer.

3. The correlation between the variation in total land inherited, reported in 2009, and total land owned in 2014 is 0.65.

   The median year of inheritance reported in 2009 is 1995.

We use information reported in the 2009 round on dry and irrigated land that was inherited as an instrument for total land size reported in the 2014 round.

2009 reports of inherited land: total dry and irrigated land.

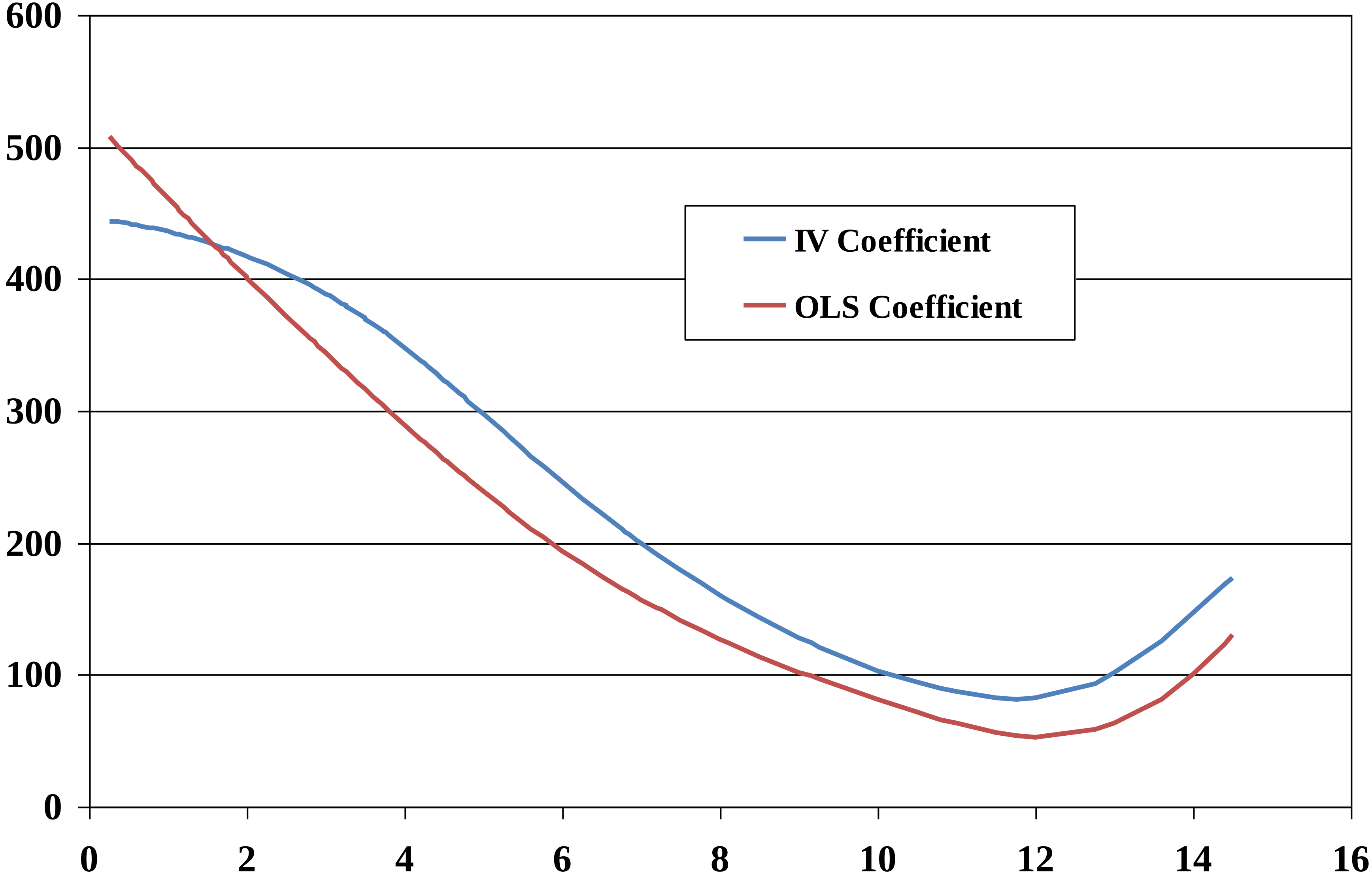
2014 total land owned = Σ plot sizes owned in 2014.

We obtain semi-nonparametric estimates of plot/land size *by land/plot size* (Cai, *et al.*, 2006).

No evidence that measurement error or plot quality is systematically related to farm size

The U-shaped patterns we see are not spurious.

Does Measurement Error Affect the IR? Profits Per Acre and Plot Size Coefficient Point Estimates, by Plot Size and Estimation Procedure



Land Allocation: Land Rental Market

(2014 Census of VLS Villages)

1. 8.4% of landowners lease out their land.

   Mean size of land leased out = 4.6 acres

2. 11.5% of landowners lease in land.

   Mean size of land leased in = 5.7 acres

3. 6.9% of landless households lease in land.

   Mean size of land leased in = 5.0 acres

Can we explain the patterns we see?
U-shaped average and rising marginal returns

Model that incorporates:

1. Fixed, transaction costs of hiring labor.

   Travel, search (for labor), storage (for equipment).

   Results in falling hourly wages with hours hired.

2. Economies of scale in equipment.

   Larger equipment more efficient than smaller units in terms of work accomplished per hour.

Input Supply: Distribution of Average Hours Worked per Day for Wages, *Kharif* Season, by Hired Input

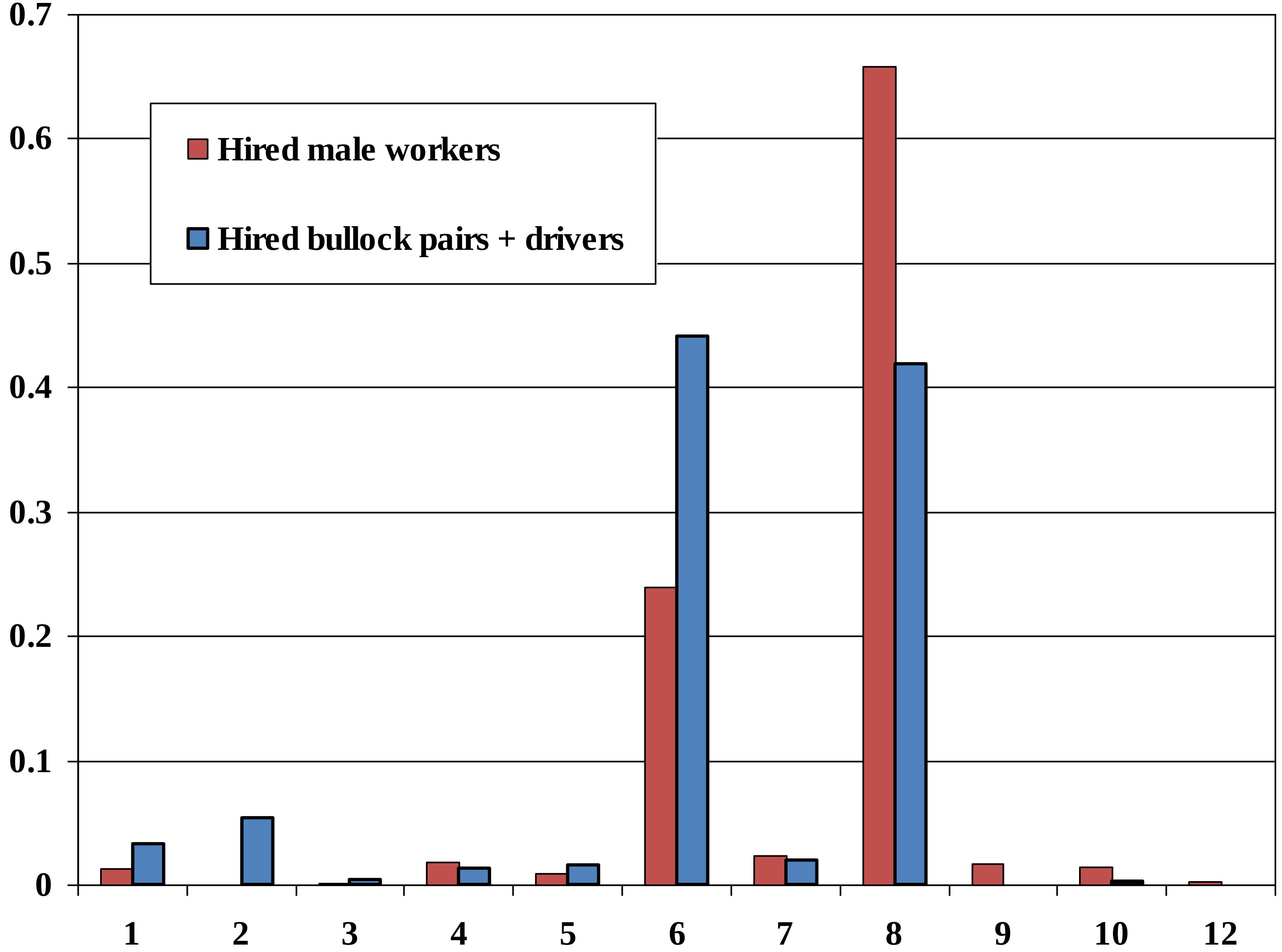
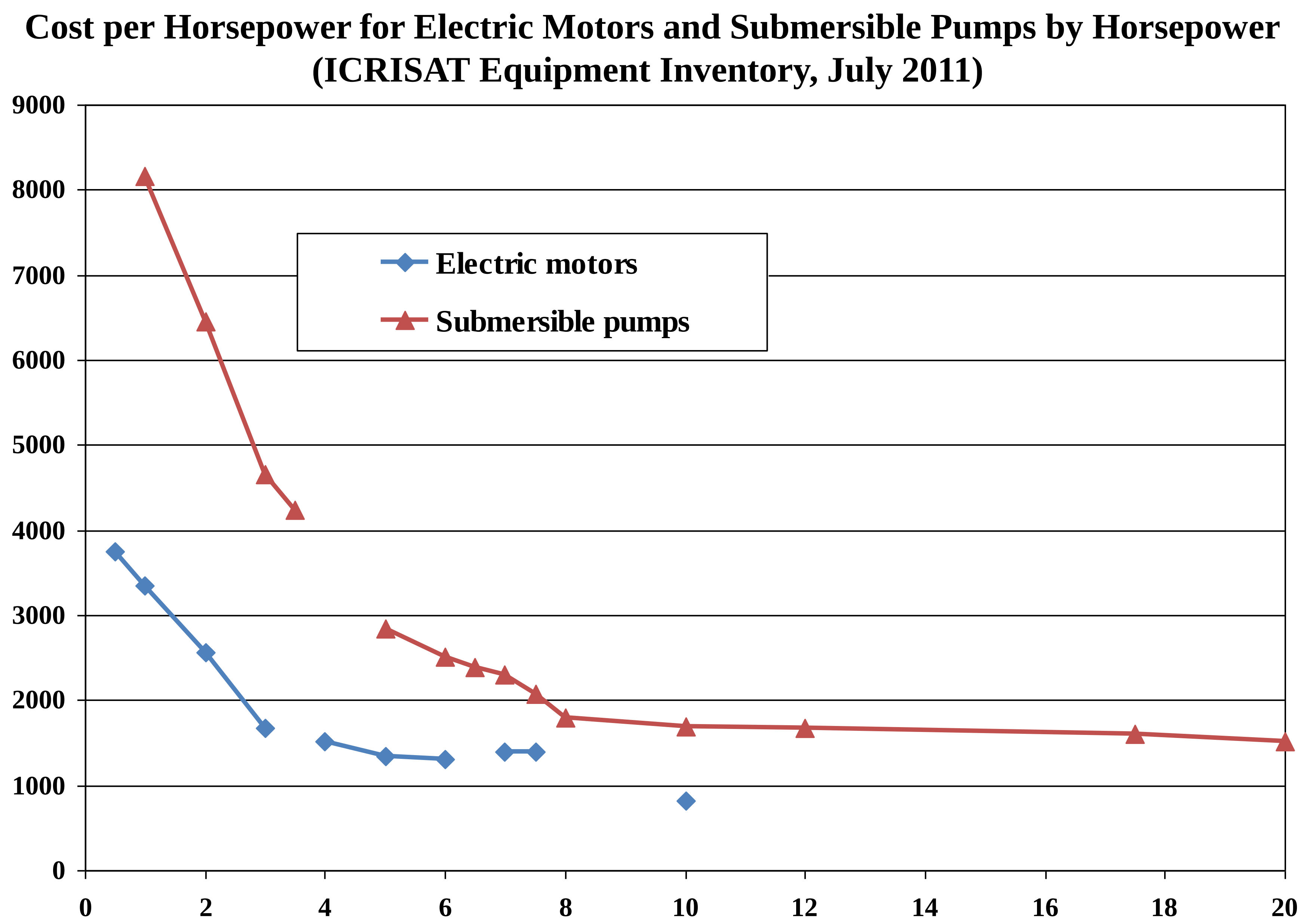


Table 2
Hourly Wage Rates and Hours Worked, by Input:
2010 and 2011 ICRISAT Monthly Price Schedules

Variable	Hired Male Labor	Hired Bullock Pair + Driver
7 - 12 hours worked	20.6	66.1
	(.369)	(1.84)
1- 6 hours worked	25.8	88.5
	(.722)	(2.84)
Difference	-5.16	-22.4
	(.741)	(3.61)
N	729	450

Standard errors in parentheses. Hourly wage rates constructed by dividing daily wages by hours worked.



Cost per Horsepower for Electric Motors and Submersible Pumps by Horsepower
(ICRISAT Equipment Inventory, July 2011)
Electric motors
Submersible pumps
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
2
4
6
8
10
12
14
16
18
20

Start with a one-task, one-period agricultural production technology in which the only variable input is labor.

Production is described by a constant returns-to-scale (CRS) production function g with one variable input, labor.

Total output is given by

$$g(a, e_1)$$

where a = land and e = work, with

$$e_1 = l_{f1} + l_{h1}\,.$$

where l_{f1} = family labor and l_{h1} = hired labor.

Workers entering the labor market for off-farm work in the period face some fixed transaction cost f per period (search, travel).

In equilibrium, employers wishing to employ workers even for just a few hours must partly compensate these workers for this fixed cost, so that the cost of hiring a worker for l_{h1} hours is

$$w(l_{h1}) = \mathbb{I}\left(l_{h1} > 0\right) w_0 + w_1 l_{h1}.$$

Farm profits π are thus

$$\pi(a, l_{h1}, l_{f1}) = ag(l_{h1} + l_{f1}) - w(l_{h1}) - w_1 l_{f1}$$

Note:

We cost out family labor at the variable component of wages.

This is correct if

(a) the family is engaged in the external labor market regardless of on farm labor supply or

(b) the transaction cost f is fully compensated by the labor market.

We assume that the farmer has a fixed endowment of labor l, and maximizes profits plus labor income minus any fixed costs of entry into the labor market.

The farmer's programming problem:

$$\max \ \mathsf{L} = \pi(a, l_{h1}, l_{f1}) + \mathbb{I}\left(l_o > 0\right)(w_0 - f) + w_1 l_o$$

subject to the constraint

$$l_o + l_h = l \ ,$$

where l_o is off-farm work.

Given the transaction cost, there will be three regimes characterizing the use of family and hired labor with two land thresholds determined by the magnitude of *f*.

Regime 1 ($a < a^*$):

At low levels of a farmers work both on farm and off farm and do not hire workers.

The critical upper bound of landholdings a^* for this regime at which the farmer is just indifferent between entering the labor market and not satisfies the two following equations:

$$g(a^*, l) = g(a^*, l_{f1}^*) + (w_0 - f) + w_1(l - l_{f1}^*),$$

$$f_l(a^*, l_{f1}^*) = w_1 .$$

Regime 2 ($a^* < a < a^{**}$):

Farmers work on farm but do not work off-farm and also do not hire workers (autarky).

The upper bound on landholdings for this regime is where farmers are just indifferent between hiring workers and not, satisfying

$$f(a^{**}, l) = f(a^{**}, l + l_{h1}^{**}) - w_0 - l_{h1}^{**},$$

$$f_l(a^{**}, l + l_h^{**}) = w_1 .$$

Regime 3 ($a > a^{**}$): Farmers work on farm and hire workers.

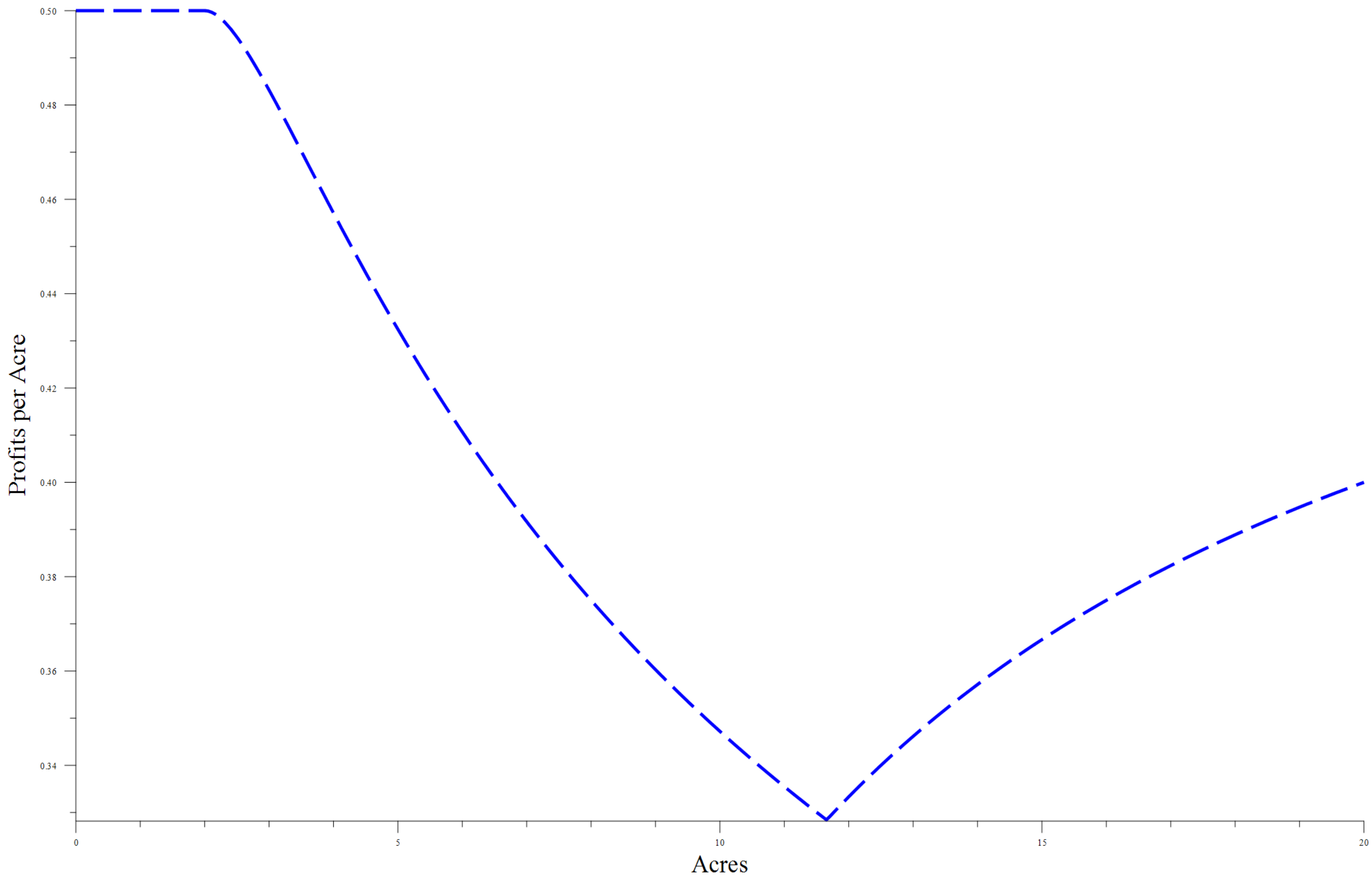
What do these regimes imply for the relationships between profits per acre and the marginal effect of acreage on profits by land size?

> Simulate model, assuming Cobb-Douglas technology with a labor share of ½, w_0=2, w=½, f = 2, l=2.

Figure 1 shows average profits by farm size - broadly consistent with what we observe in our data and in most of the literature for average profitability:

> Relatively high profits per acre on small farms, followed by a decrease and subsequent increase in profits per acre – in this case around 10 acres. The profits per acre for the largest farms remains below that of the smallest farms.

Figure 1. Average Profits and Land Size: Labor Only Case



Specifically we see the effects of the three regimes with respect to average profits:

On small farms, workers are working off farm and thus changes in acreage have no effect on profits per acre.

At 2.5 acres the farm becomes autarchic with respect to labor. At this stage profitability per acre declines as acreage increases because family labor is constant.

At 11.8 acres in the simulation the farm begins to hire workers so average profitability starts to rise.

So, it would seem small farms are optimal. But, not if we look at marginal returns.

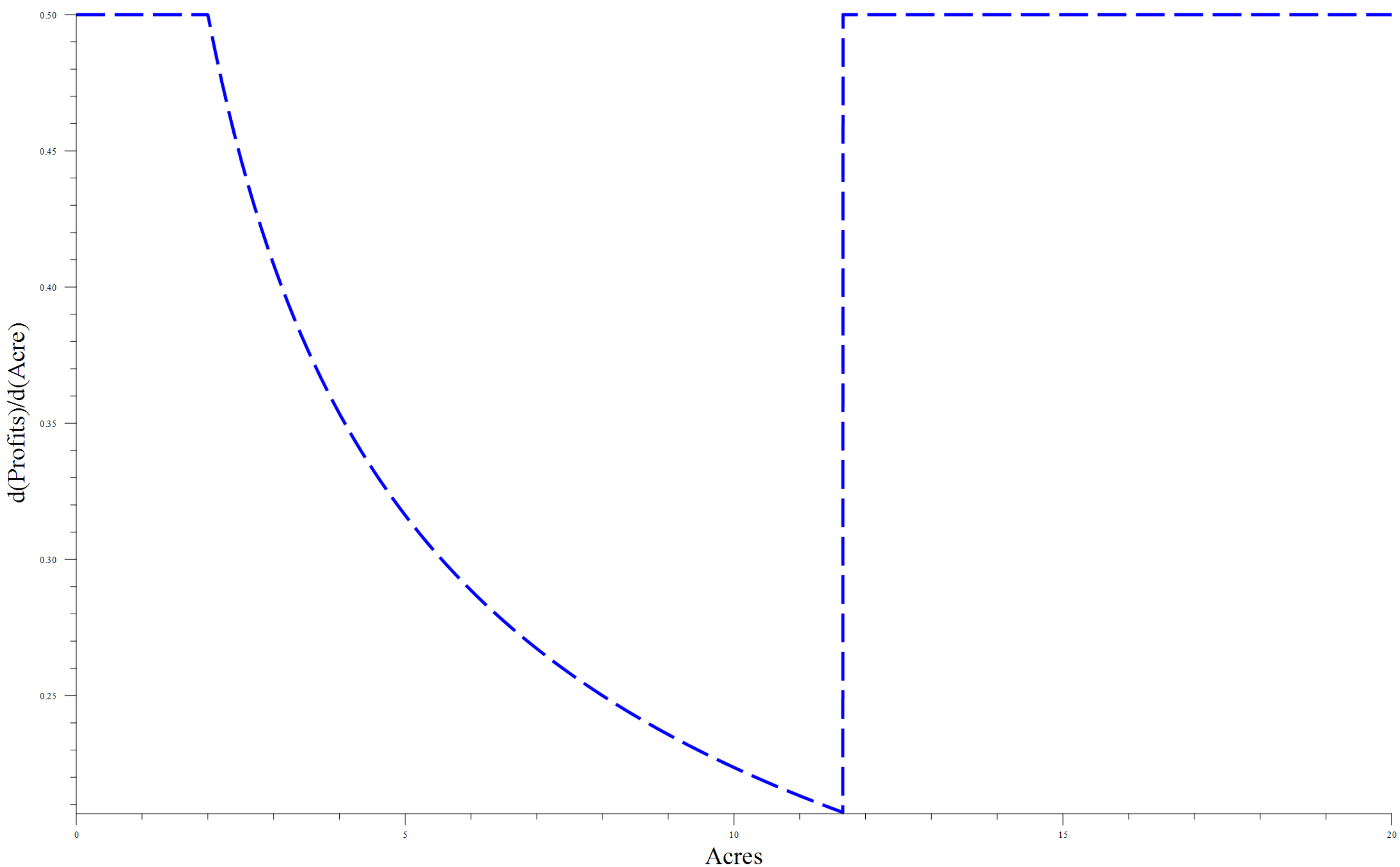
Figure 2 plots the corresponding marginal profit effects of scale as a function of acreage.

> There is a drop in the marginal return for intermediate farms but the marginal return is the same for the smallest and largest farmers.

Thus, from an efficiency perspective (maximizing land returns) redistributing land from intermediate to *either* larger or smaller farms can be justified.

Note that this result is clearly different from one might conclude based on Figure 1, which would incorrectly suggest a clear preference for smaller farms.

Figure 2. Marginal Returns to Profits and Land Size: Labor Only Case



Now we add machines, which can substitute for labor in supplying work and have can have different capacities.

To capture these ideas we redefine the work production function:

$$e(l,q,m) = (\omega_l l^{\delta} + \omega_m ((\phi(a) - q)qm)^{\delta})^{1/\delta}$$

where q = the capacity of the machinery, m = the amount of time the machine is employed, and δ reflects the substitutability between labor and machines

$\phi(a)$, with $\phi'(a) > 0$, captures how machine productivity changes with land size (larger machines can only be used on larger plots).

The cost of per unit of time of a machine of capacity q is

$$p_q q^{\nu}$$

Thus the machine cost per-time-unit rises with capacity, but at a declining rate (which is what we see in the price schedules for equipment)

Profits are now redefined as

$$\pi(a, l_{h1}, l_{f1}, m_1) = g(a, e_1(l_{h1} + l_{f1})) - w(l_{h1}) - w_1 l_{f1} - p_q q^{\nu} m_1$$

Efficient capacity requires that

$$q = \frac{1-\nu}{2-\nu}\phi(a),$$

Thus, higher capacity machines are used on larger farms. Optimal machine and labor hours are then selected to maximize profits, given optimal machine capacity.

We can also simulate this augmented model, computing average and marginal profitability by land size.

In addition to the parameter values in the labor-only model, we set δ=½, p=1,v=½, and $\varphi(a)$=0.002*a^2.

Figure 3 displays average profits with and without the option for machine employment. The simulation with the machinery option also replicates the u-shaped relationship between farm (plot) size and average profits we see in the data.

> However average profits rise more rapidly with scale compared with the labor-only model, as, for example, farmers need never exit the autarchy regime to hire more expensive labor.

Figure 4 shows marginal profit effects of land size by scale in the augmented model compared with the labor only model.

Figure 3. Average Profits and Land Size, Labor and Machinery

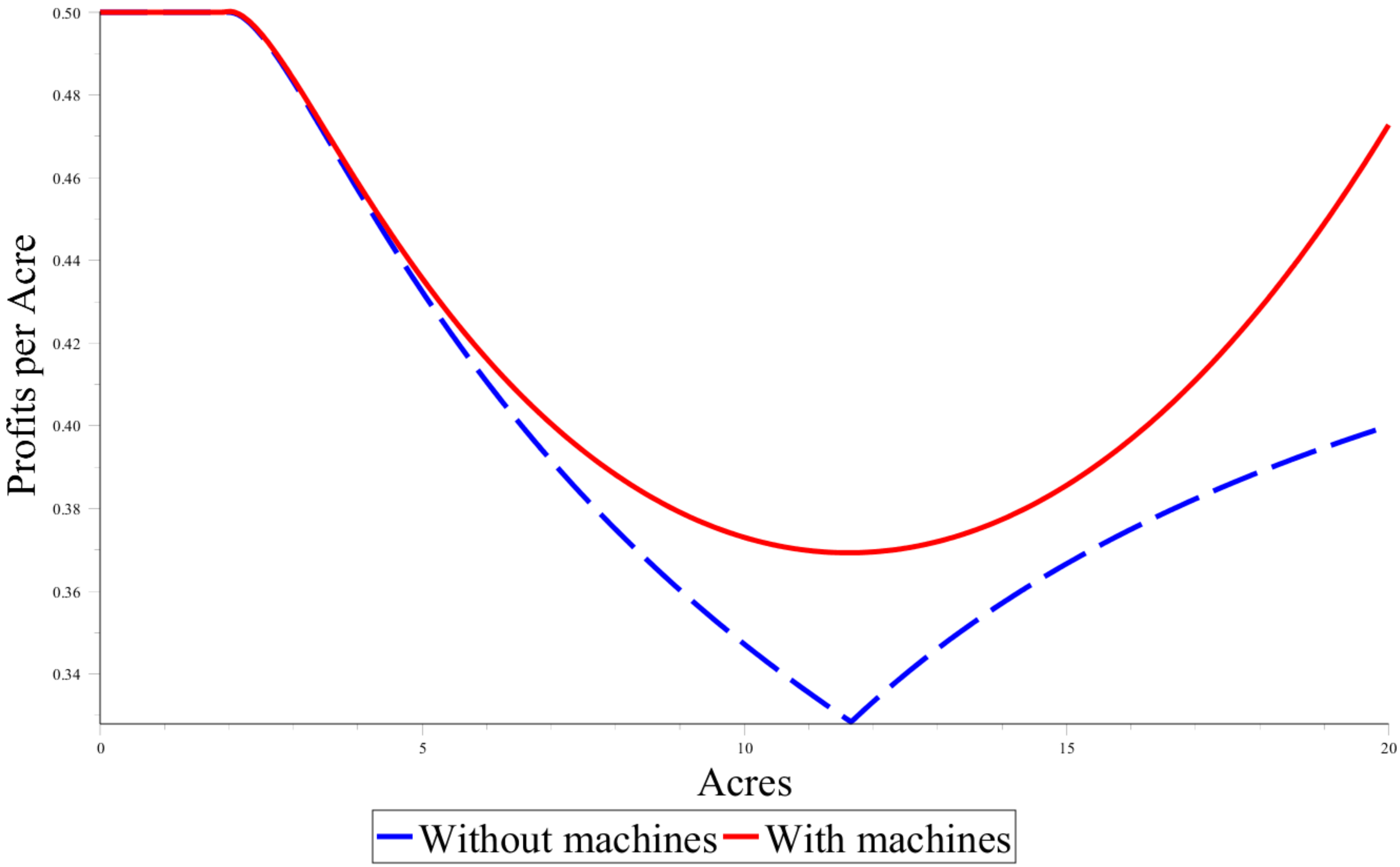
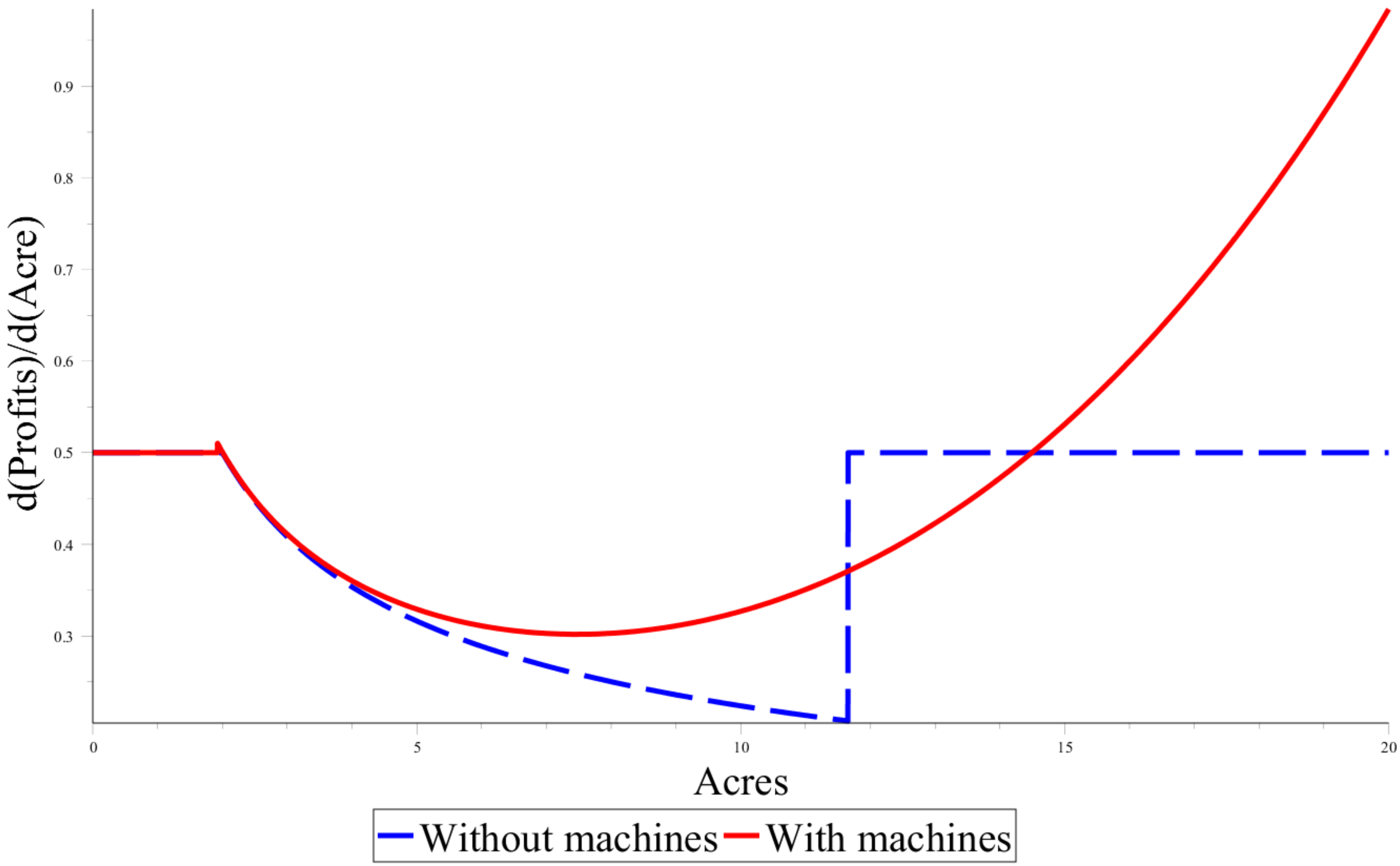


Figure 4. Marginal Profit Returns and Land Size: Labor and Machinery



In the full model, the marginal returns to increasing scale:

Rise with farm size after 10 acres

Are higher for larger compared with smaller farms.

Thus, the presence of fixed costs associated with input hiring and scale economies in machinery:

Match the patterns for average and marginal profitability by farm scale in the data.

Imply that a re-allocation of land from small and intermediate to large farms unambiguously increases the return to land.

The question is, should we believe this model?

Methods for Testing

Estimate the relationship between plot size, input use, input unit costs, and work accomplished by plot size.

Exploit panel data at the plot level.

Control for village-year fixed effects (weather, price shocks), plot characteristics, and farmer characteristics.

Also estimate within-farmer and within-plot effects where relevant.

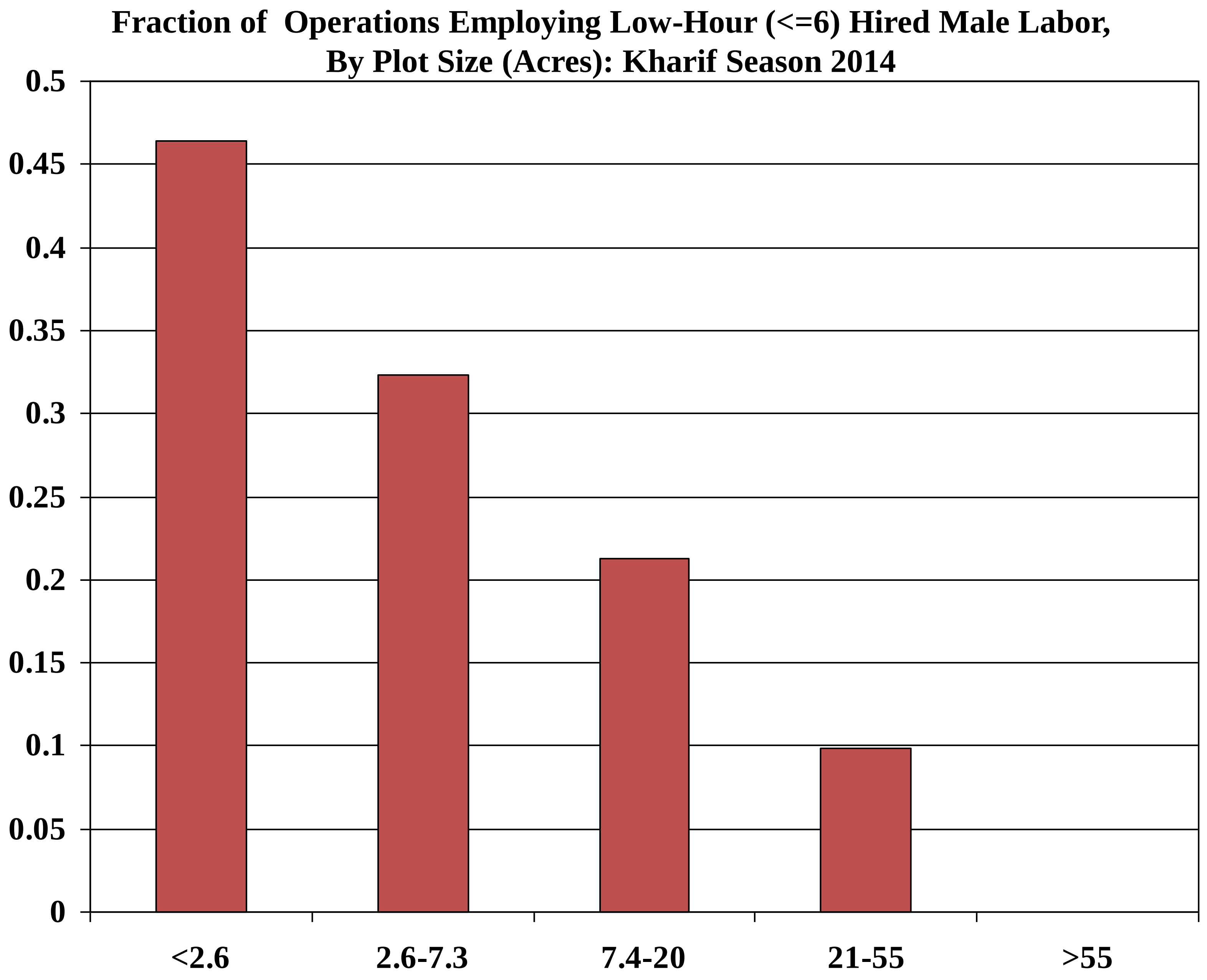
Tests:

A. Do we see rising use of low-hour inputs per operation as plot size increases at low scales? Yes.

B. Because of transaction costs, do we as a consequence see average unit input costs rising with scale at low scales? Yes.

C. Using *plot fixed effects*, do we see that increases in rainfall lower low-hour input use and unit input costs? Yes.

D. Do we see evidence of scale economies from using mechanized equipment (ex: sprayers)? Yes.



Fraction of Operations Employing Low-Hour (<=6) Hired Male Labor, By Plot Size (Acres): Kharif Season 2014
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
<2.6
2.6-7.3
7.4-20
21-55
>55

Table 3
Plot Size and Fraction of Operations that Employ Hired Inputs at Low (<=6) Daily Hours and the Average Hourly Wage Paid, by Input Type
(*Kharif* Seasons 2009-2014)

Variable	Fraction of Operations <6 Hours/Day			Average Hourly Wage		
Input type	Hired Male Labor	Hired Tractor	Hired Bullock Pair	Hired Male Labor	Hired Tractor	Hired Bullock Pair
Plot size (acres)	-.0165	-.0197	-.0170	-.183	1.25	-.866
	(.00306)	(.00247)	(.00306)	(.0876)	(.769)	(.306)
Plot size squared x10^{-3}	.450	.449	.555	8.29	18.3	29.3
	(.112)	(.0682)	(.117)	(3.23)	(32.4)	(10.9)
Village/year FE	Y	Y	Y	Y	Y	Y
25 Plot and household characteristics	Y	Y	Y	Y	Y	Y
Number of observations	6,777	6,777	6,777	6,777	6,777	6,777

Standard errors in parentheses clustered at the village/year level.

Table 4
Plot Fixed Effects Estimates: The Effects of *Kharif*-Season Rainfall on Profits, Hours Employed and Average Hourly Wage Rates, by Input Type
(Kharif Seasons, 2009-2014)

Variable	Profits	Hours Employed			Average Hourly Wage		
Input type	-	Hired Male Labor	Hired Tractor	Hired Bullock Pair	Hired Male Labor	Hired Tractor	Hired Bullock Pair
Rainfall (mm)	38.1 (17.1)	.182 (.0701)	.00362 (.00316)	.0347 (.0248)	-.0158 (.00672)	.0130 (.0601)	-.0593 (.0355)
Rainfall squared $x10^{-3}$	-21.2 (8.59)	-.107 (.0377)	-.00214 (.00161)	-.0500 (.0268)	.00778 (.00398)	-.0132 (.0282)	.0757 (.0331)
Year FE	Y	Y	Y	Y	Y	Y	Y
H_0: Rain and rain squared = 0 F(2,n) [p]	3.09 [.0504]	4.18 [.0183]	0.99 [.3742]	1.97 [.1452]	3.47 [.0352]	0.28 [.7589]	3.02 [.0538]
Number of observations	5,291	3,987	4,016	2,523	3,987	4,016	2,523

Standard errors in parentheses clustered at the village/year level.

Sprayers

Spraying weedicide and insecticide is an important operation:

Spraying labor costs alone account for 13.6% of total input costs in the *Kharif* season.

There are two types of sprayers used by ICRISAT farmers:

Manual sprayers, median cost (2014 rupees) = 700

Power sprayers, average cost (2014 rupees) = 2700

Even among power sprayers, there are different capacities.

Pricing schedule: exhibits equipment economies of scale.

Manual and Power Sprayers

Table 5
Cost and Capacities of Indian *KrisanKraft* Power Sprayers, 2017

Power sprayer	Litres/Hour	Current Price (Rupees)
	180	7,830
	420	12,260
	1320	25,900
	2400	27,900

Farmers with larger landholdings are more likely to own power sprayers, net of wealth effects.

We also test to see if:

A. As plot size increases, per-hour costs of the sprayer increase: suggests the use of more powerful sprayers.

B. As plot size increases there is more output (material sprayed) per-acre from spraying.

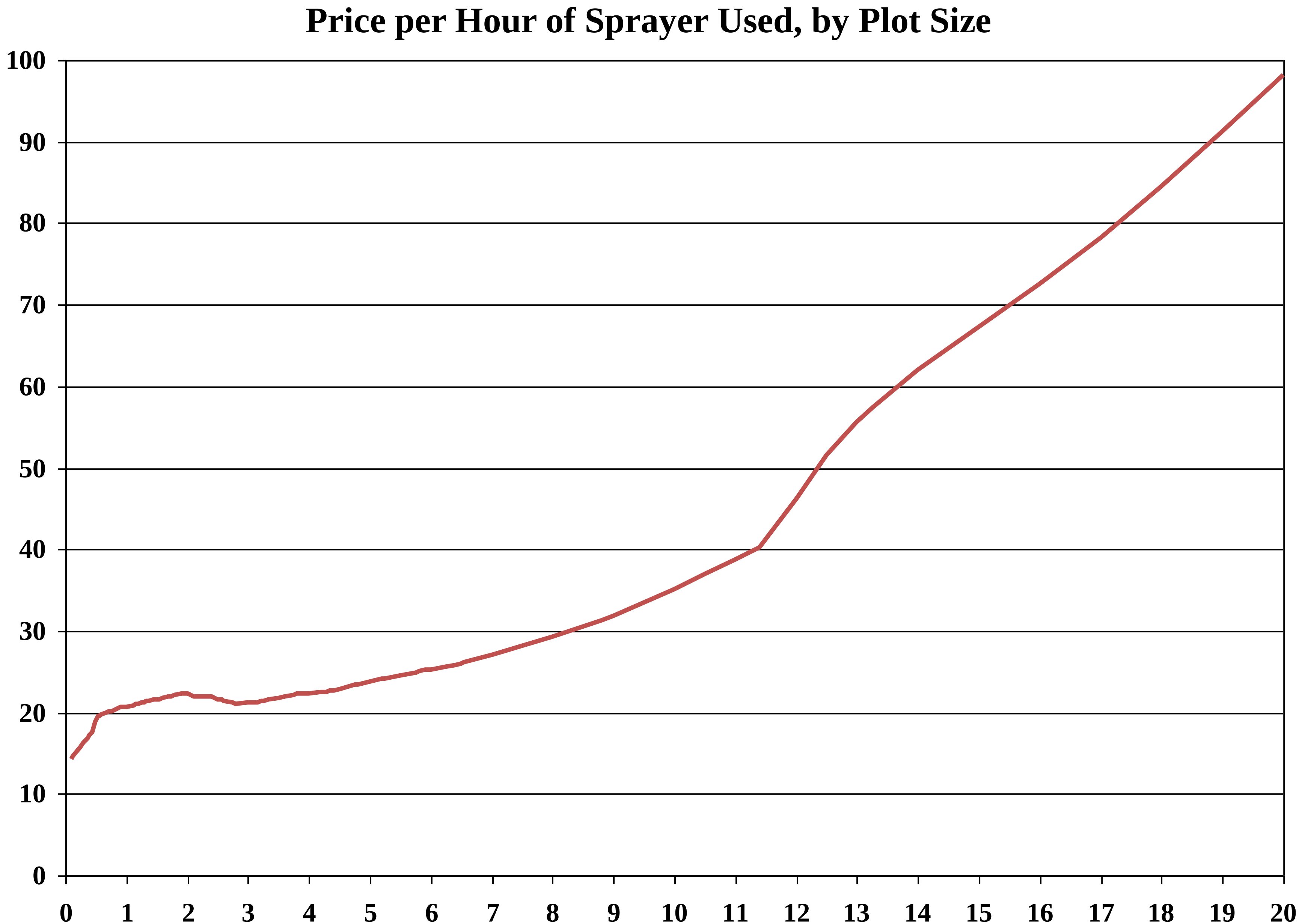
    We have information on the amount of spraying material used (weedicide, insecticide).

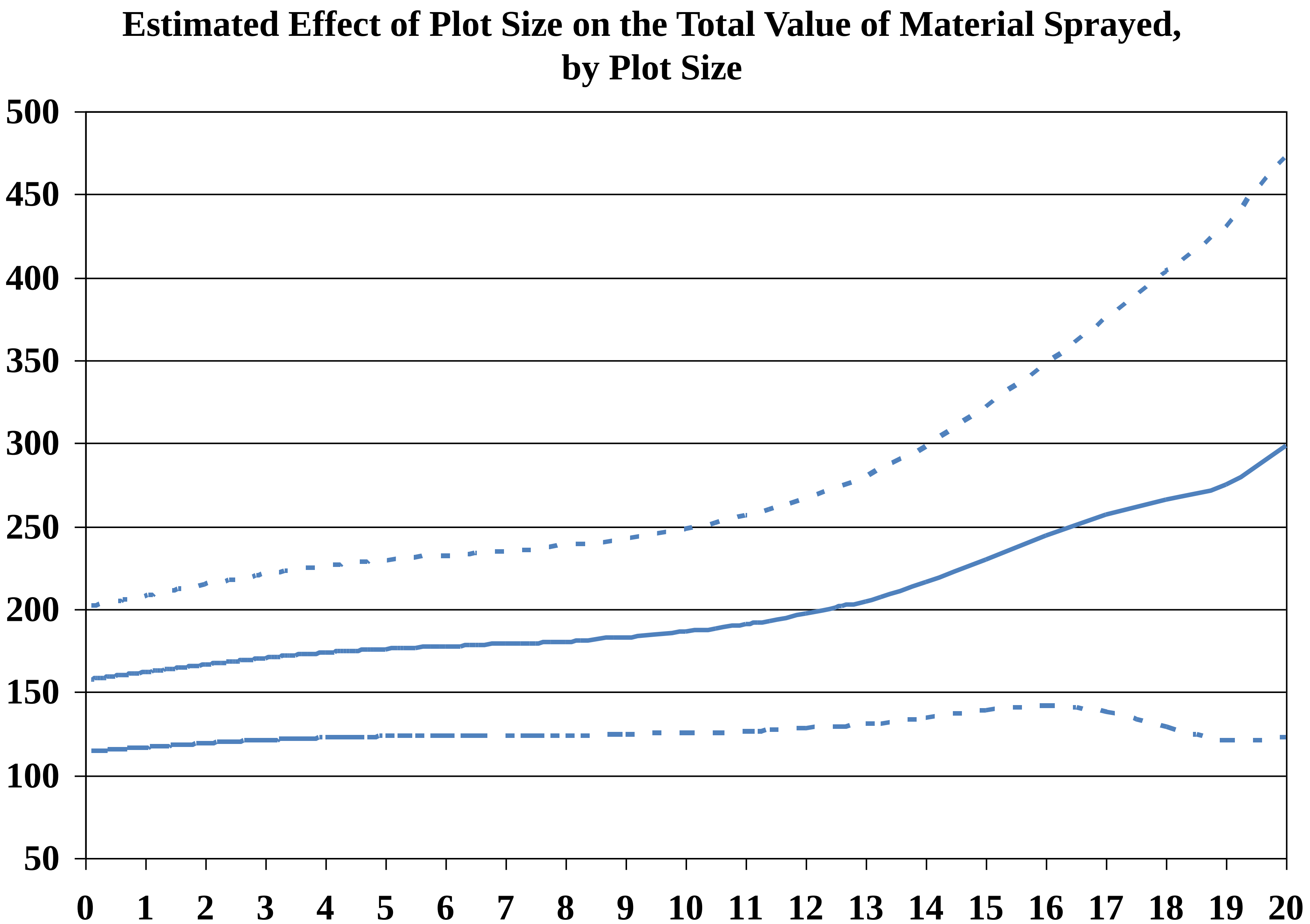
B. As plot size increases, total labor costs per-acre for labor used in spraying per acre declines.

Table 6
Farm Size, Wealth and Mechanization (Ownership): 2014 ICRISAT Round

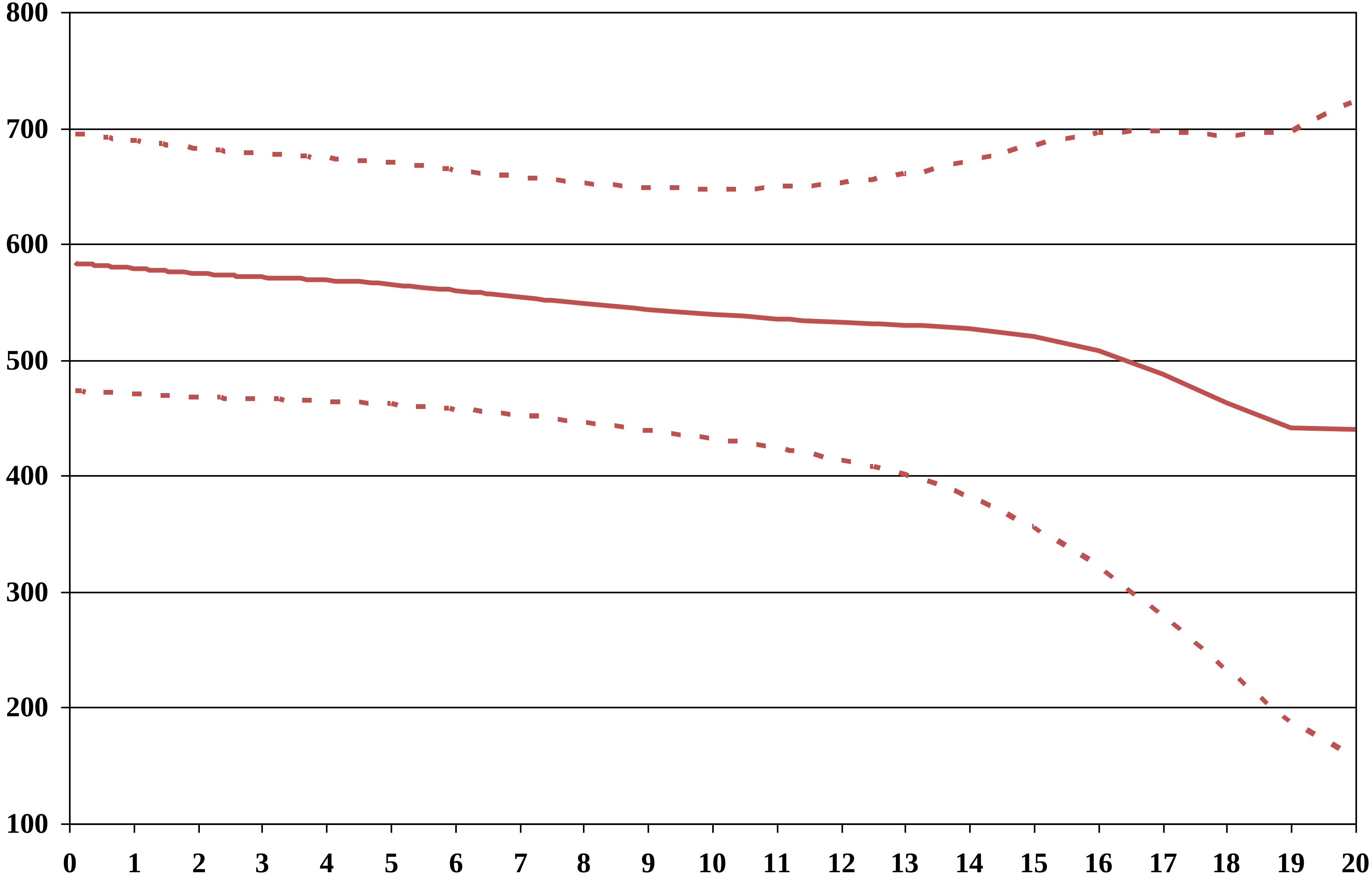
Variable	Owns a Tractor	Owns a Power Sprayer	
Sample	All Farmers	All Farmers	Farmers Who Own Any Sprayer
Size of total owned land (acres)	.0125 (.00415)	.0107 (.00474)	.0133 (.00494)
Total rental value of land (wealth) x 10^{-5}	.0506 (.0146)	.0512 (.0166)	.0273 (.0144)
Village FE	Y	Y	Y
Percent owning	3.5	10.3	24.8
Number of farmers	652	652	288

Standard errors in parentheses clustered at the village level. All specifications include the head's age and schooling.


Price per Hour of Sprayer Used, by Plot Size
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20


Estimated Effect of Plot Size on the Total Value of Material Sprayed,
by Plot Size
500
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

Estimated Effect of Plot Size on the Total Labor Cost of Spraying, by Plot Size



Estimated Effects of Plot Size on the Total Labor Cost of Spraying and the Total Value of Material Sprayed, by Plot Size