

Labor Market Frictions and Development

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STEG Virtual Course on 'Key Concepts in Macro Development'

The focus of this lecture will be on labor market frictions in agriculture in low-income countries.

Frictions exist in the industrial sector, many of which are legislative. But will not be discussed here.

Agriculture is the largest industry in most low-income countries.

The frictions in the ag labor market are “natural” not *de jure*.

Agricultural production takes place in a series of operations.

The timing and length of these operations is unknown *ex ante*.

The episodic and stochastic nature of production combined with small scale rules out relational contracting of labor.

Labor in agriculture is hired, if at all, on a daily basis: there are search costs associated with travel, for example.

In this lecture:

We will quantify these transaction costs - they are large.

We will show who pays them.

We will embed these frictions in a model of agricultural production.

We will show using the model what role these frictions play in lowering productivity via the mis-allocation of labor on (under-utilization) and across farms of different scale.

We will test the implications of the model with labor-market transactions costs (micro development).

We will calibrate the model and assess how well it captures the principal features of agriculture (macro development).

We will carry out a counterfactual land reform policy using the estimated and calibrated parameters that induces a structural adjustment - what happens to output? income per-capita? the size of the labor force?

Note: there is no practical policy that eliminates or reduces labor market frictions in agriculture in the absence of other changes.

Land reforms have taken place in many countries.

In examining agriculture in low-income settings, cannot ignore the role of scale.

The small scale of farms is the key difference between low-income, low productivity agriculture and agriculture in high-income countries.

We need to look at the big picture to understand the roles of labor market frictions.

This includes the role of mechanization.

Machines can substitute for labor and thus reduce the cost of labor market frictions: farmers have an incentive to mechanize.

But, low-income farming is not mechanized. Why not?

1948 United Provinces Zamindari Abolition Committee Report:

“... the most dominant as well as the most intractable feature of our agrarian economy is the small size of the holding occupied by the vast majority of the cultivators. No effective solution of the problem of improved production and the crushing burden of poverty can be found until we devise a system in which the unit of agricultural organisation will not ordinarily be below the minimum unit.”

What is that minimum unit? What is optimal farm size in India?

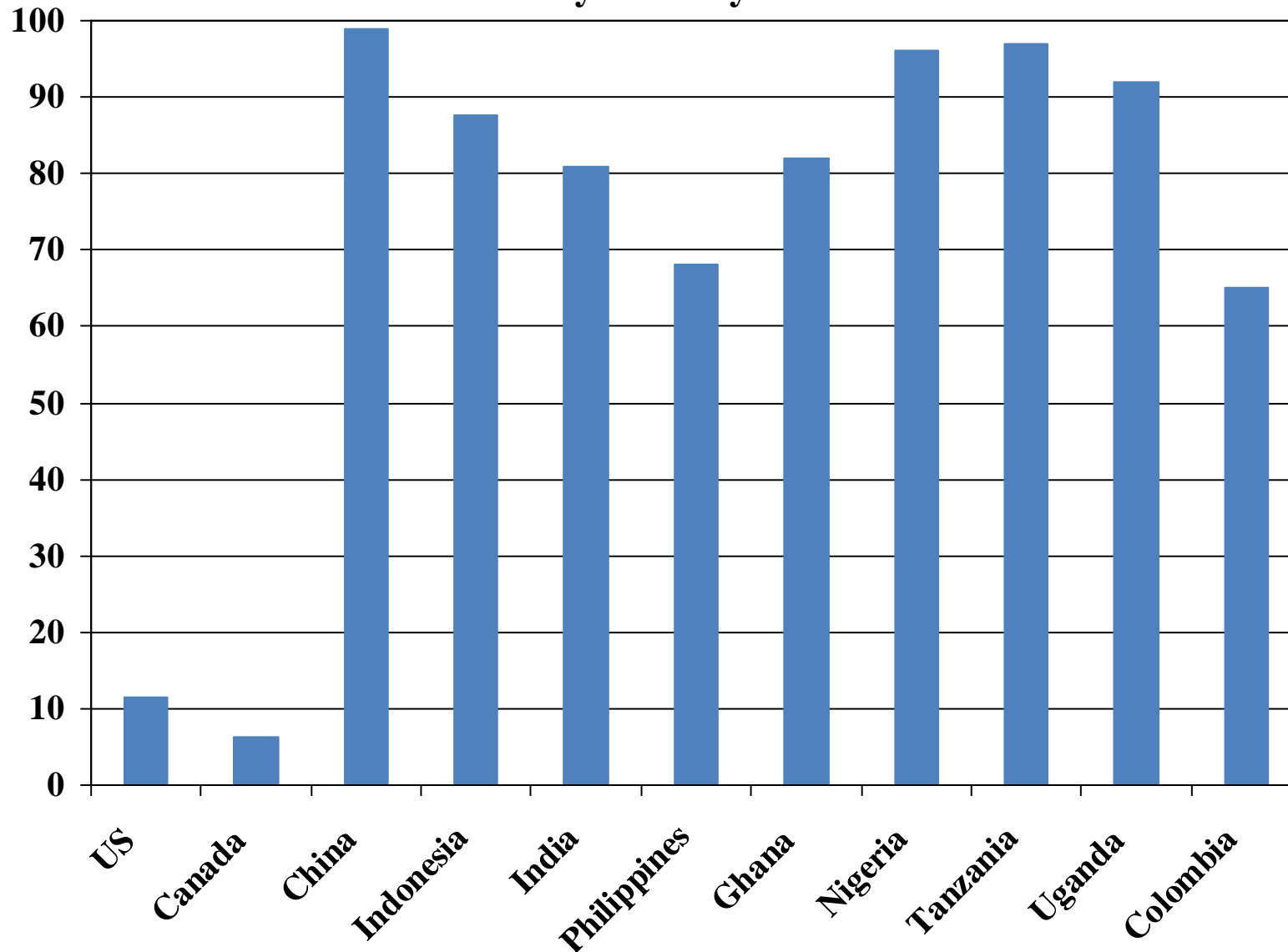
In the report, the “economic” land size was determined to be 10 acres, based on the ownership of “a good pair of bullocks.”

Ignored labor costs, and of course, today, modern machinery.

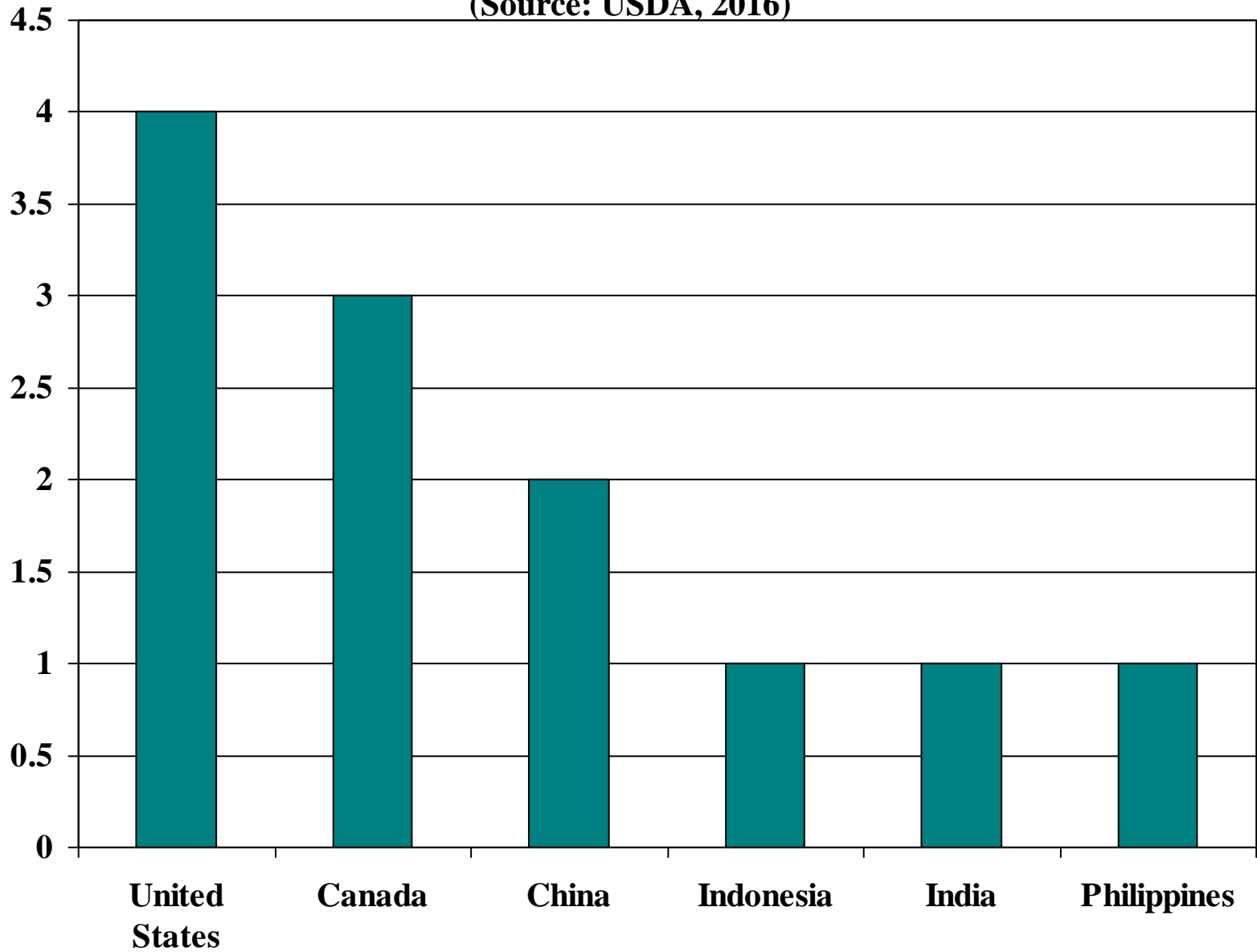
Four global facts:

- A. Farming in low-income countries is small scale; farming in developed countries is large scale.
- B. Productivity of developed country farming is higher than the productivity of farms in low-income countries.
- C. Within low-income countries there is an almost universal inverse relationship between farm size and productivity.
- D. Within low-income countries, a large fraction of operations take place in autarchy - no hired labor, no off-farm labor.
- E. Within high-income countries with mechanized agriculture, scale economies are positive even at very large acreages.

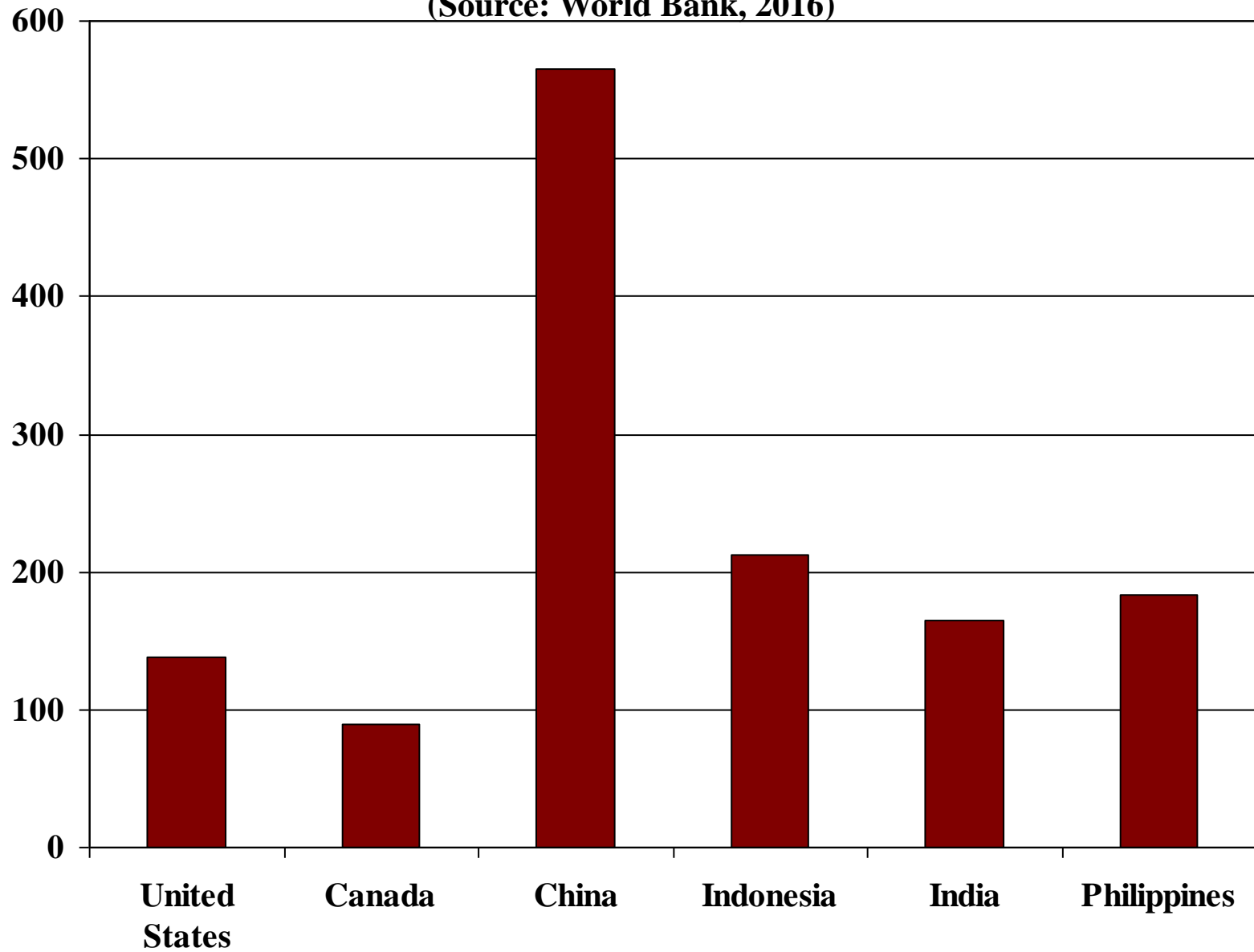
Percent of Households with Operational Landholdings Below 10 Acres, by Country



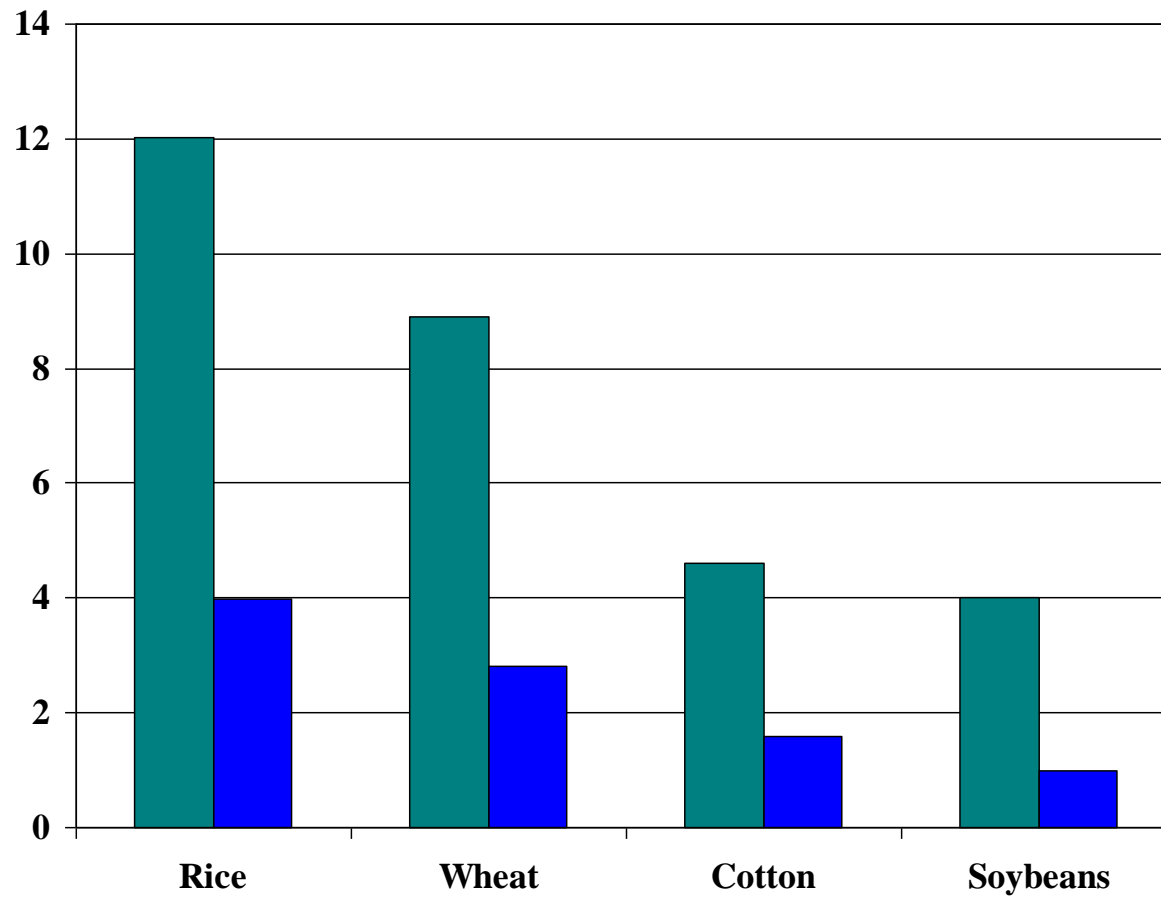
Soybean Yields (Metric Tons per Hectare) in 2016, by Country
(Source: USDA, 2016)

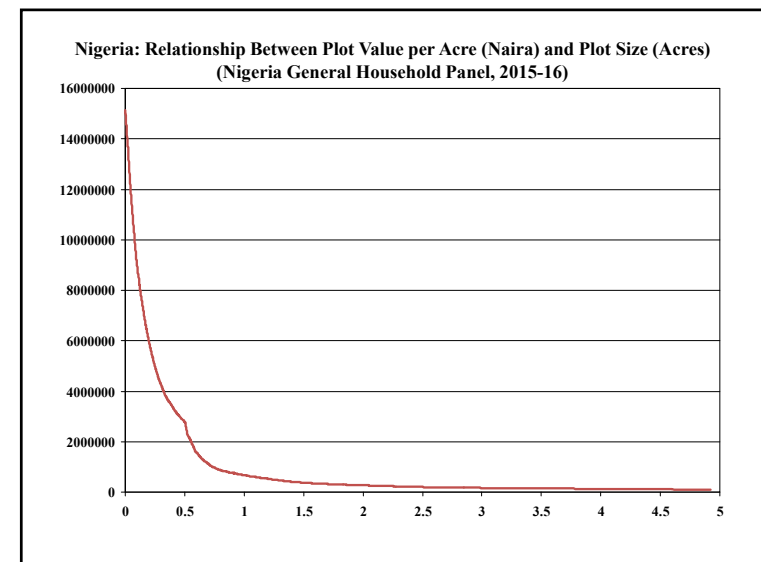
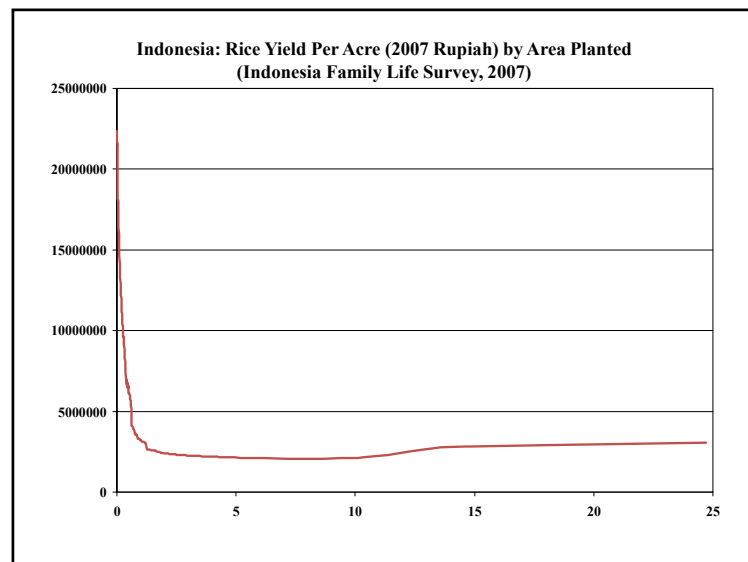
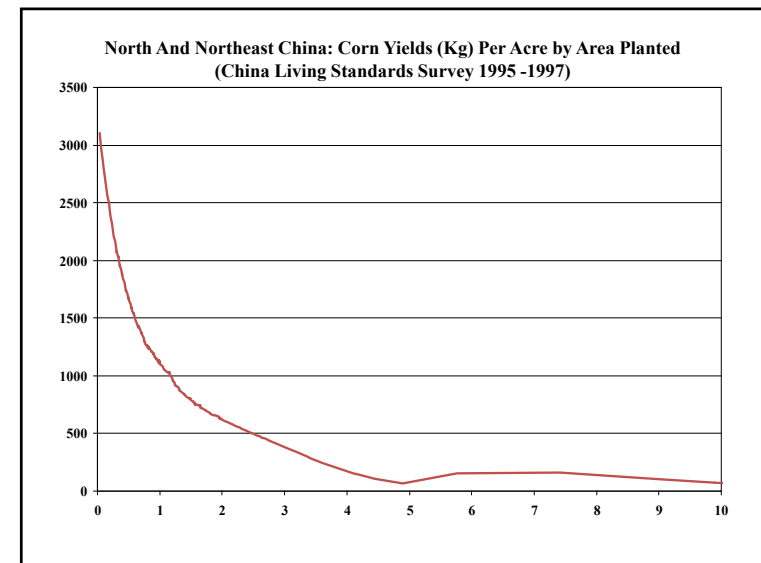
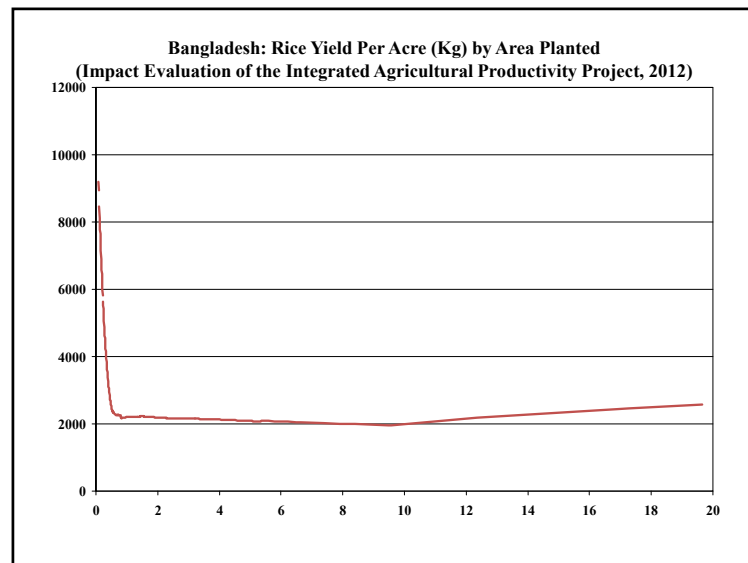


Fertilizer Intensity (Kilograms per Hectare) in 2014, by Country
(Source: World Bank, 2016)



**Yields (Metric Tons per Hectare) in 2012, by Crop
India (Blue) versus Best Producer (Green)**





Autarchic Farming

Farming takes place in a series of sequential operations.

In Nigeria (Nigeria LSMS Agricultural Survey, 2015-16), 36.2% of planting operations are autarchic.

In China (North and Northeast China Survey, 1995), across a whole season, all operations for 17.2% of farms were autarchic.

In India (ICRISAT VLS 2014) 33.8% of all operations were autarchic.

Autarchic farming concentrated among the lowest plot sizes.

Figure A. Lowess-Smoothed Relationship of the Fraction of Autarchic Plots by Plot Size, (ICRISAT Survey, 2014)

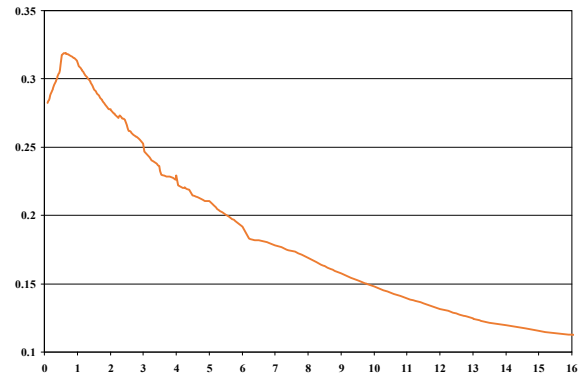


Figure B. Lowess-Smoothed Relationship of the Fraction of Autarchic Plots by Plot Size, (Nigeria LSMs Agricultural Survey, 2015-16)

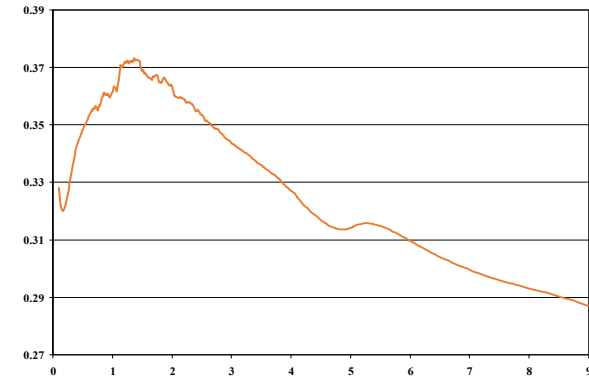
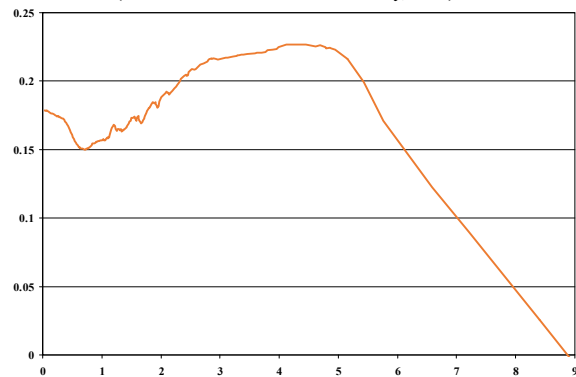


Figure C. Lowess-Smoothed Relationship of the Fraction of Autarchic Plots by Plot Size, (North and Northeast China Survey, 1995)




Supersized Family Farm

https://www.wsj.com/articles/the-family-farm-bulks-up-1508781895

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Supersized Family Farms Are Gobbling Up American Agriculture

U.S. growers are swallowing up acreage to survive a harsh agricultural downturn, squeezing smaller operations and transforming America's rural economy.

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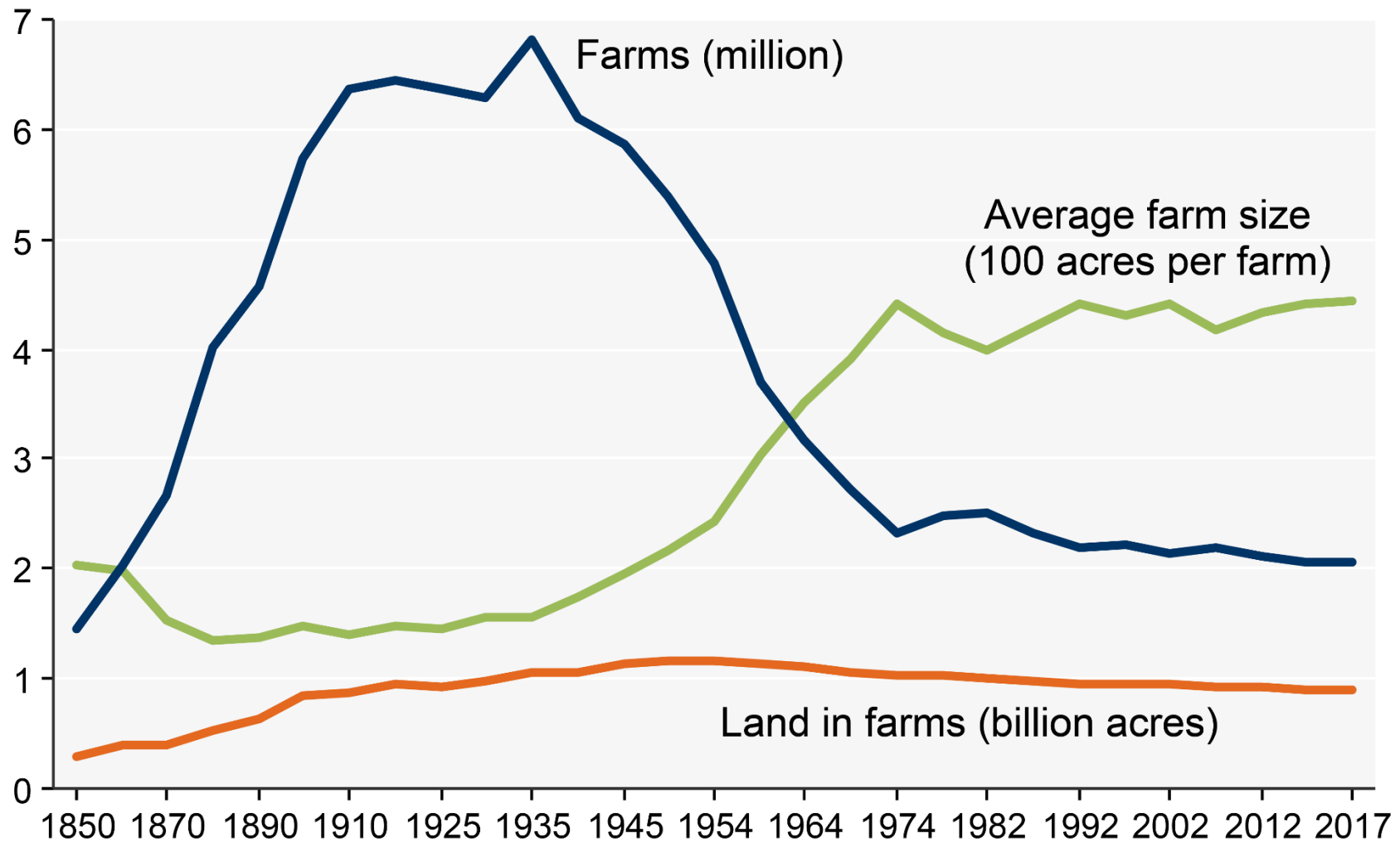


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Farms, land in farms, and average acres per farm, 1850-2017

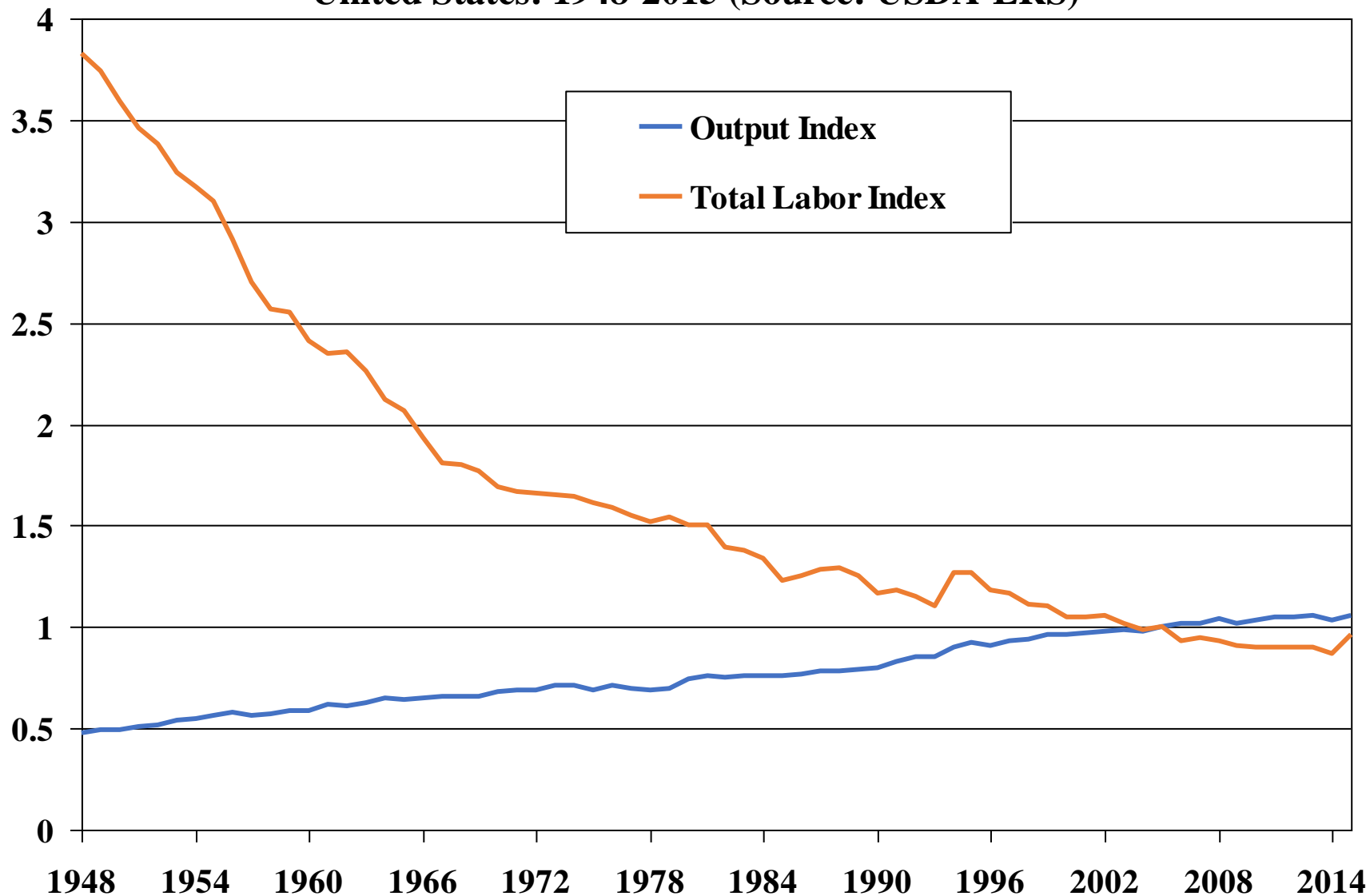
Million farms, billion acres, or 100 acres per farm



Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, Census of Agriculture (through 2012) and *Farms and Land in Farms: 2017 Summary*.

Indices of Total Farm Output and Total Labor Inputs, by Year

United States: 1948-2015 (Source: USDA-ERS)



The existence of any larger farms in low-income countries thus appears to represent a mis-allocation of farmland.

Many land reform programs limit the size of farms, consistent with the documented inverse productivity scale relationship.

Such policies seem at odds with the observed global differences in agricultural productivity and farm scale.

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

The question of farm size is a “big” question for development:

A large fraction of the labor force is employed in agriculture on small farms in low-income countries

(India: 119 million farms, 25% of labor force)

The “inverse-relationship” productivity stylized fact appears to have led to complacency about the issue of scale.

But, if there are positive scale economies, then this could imply that:

The exit of farmers (and the consequent expansion of farm sizes) would not decrease agricultural output (and might increase it) - surplus labor!

Challenges to Identifying Scale Economies

1. Span of the distribution of plot/land sizes limited in most low-income countries - you simply can't observe the productivity of large farms.
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 productivity-relevant characteristics of equipment used: capacity (e.g, horsepower, work accomplished by acreage).

Outline

1. Describe the data used (India) and show the land distribution and the relationship between profits and output per acre and land size.
2. Assess whether the observed pattern is just: measurement error in size, plot quality, wealth effects and farmer ability.
3. Quantify the importance of labor-market hiring costs.
4. Model - incorporating transaction costs in hired labor and economies of scale in farm equipment.
5. Tests of implications of transaction costs in the labor market.

6. Assess whether there are economies of scale in equipment: focusing on sprayers: price schedules for machine capacity, capacity by area.
7. Estimate structural parameters relevant to equipment scale economies.
8. Calibrate the model in an equilibrium context (labor exit) to:
 - A. Identify the optimal scale of farms, given existing machine technology in India.
 - B. Carry out a counterfactual in which all farms are at the conditional optimum: total output, output per worker
9. Conclusion: identification of barriers to changing scale.

Data: ICRISAT India VLS data set

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

20 villages in 6 states

819 farmers

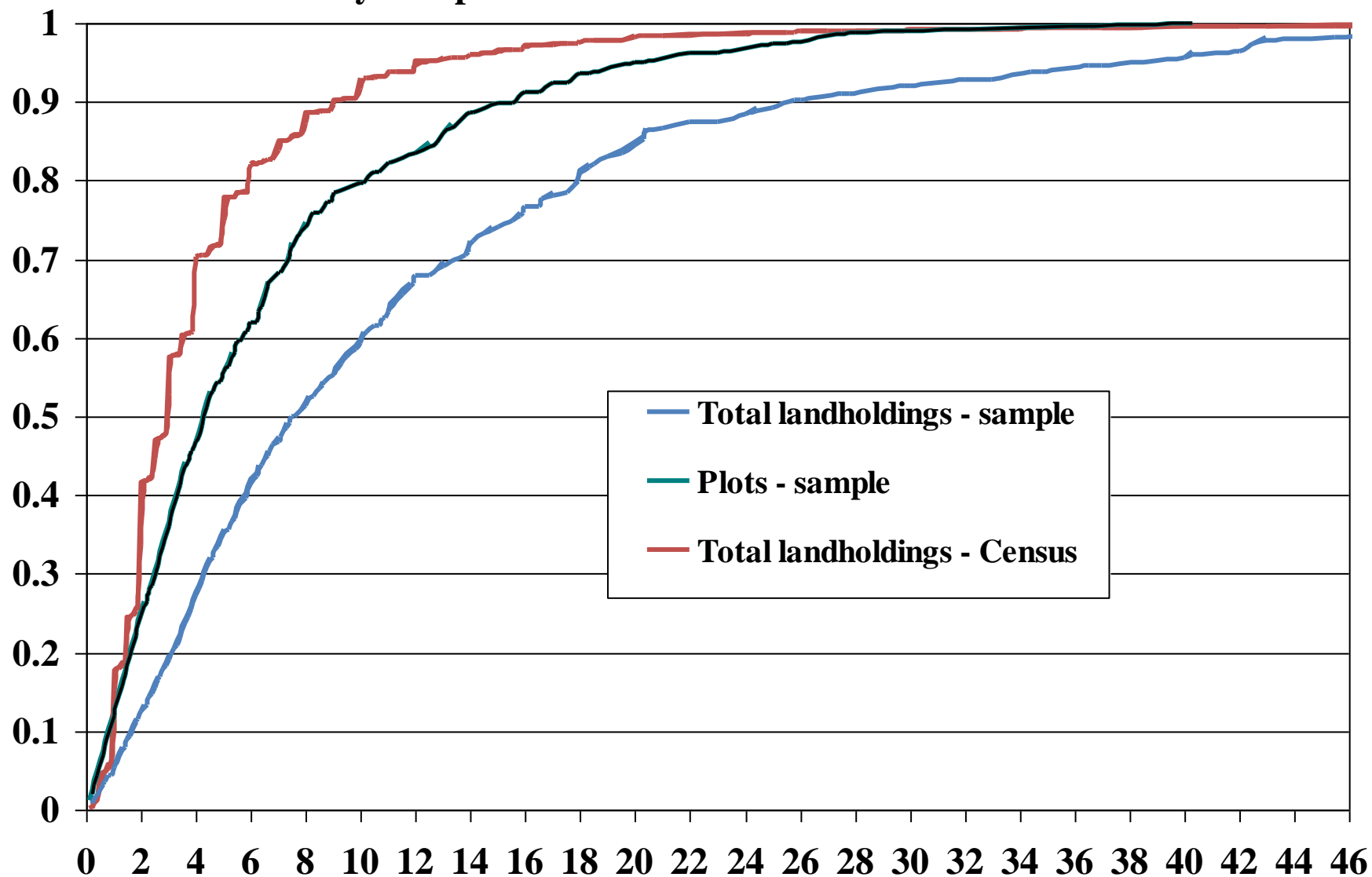
2,015 plots

Complete census of all households in the 20 villages.

Sampling frame of survey - stratification by farm size, so *over-sampling of larger farms*:

Four equal-sized groups: none, small, medium, large

**Cumulative Distributions of Owned Total Land and Land Plots (Acres),
By Sample and Census: ICRISAT VLS 2014**



Information on input quantities and prices by type of input and outputs *by operation* and individual plot (every three weeks).

Multiple measures of plot quality and farmer ability.

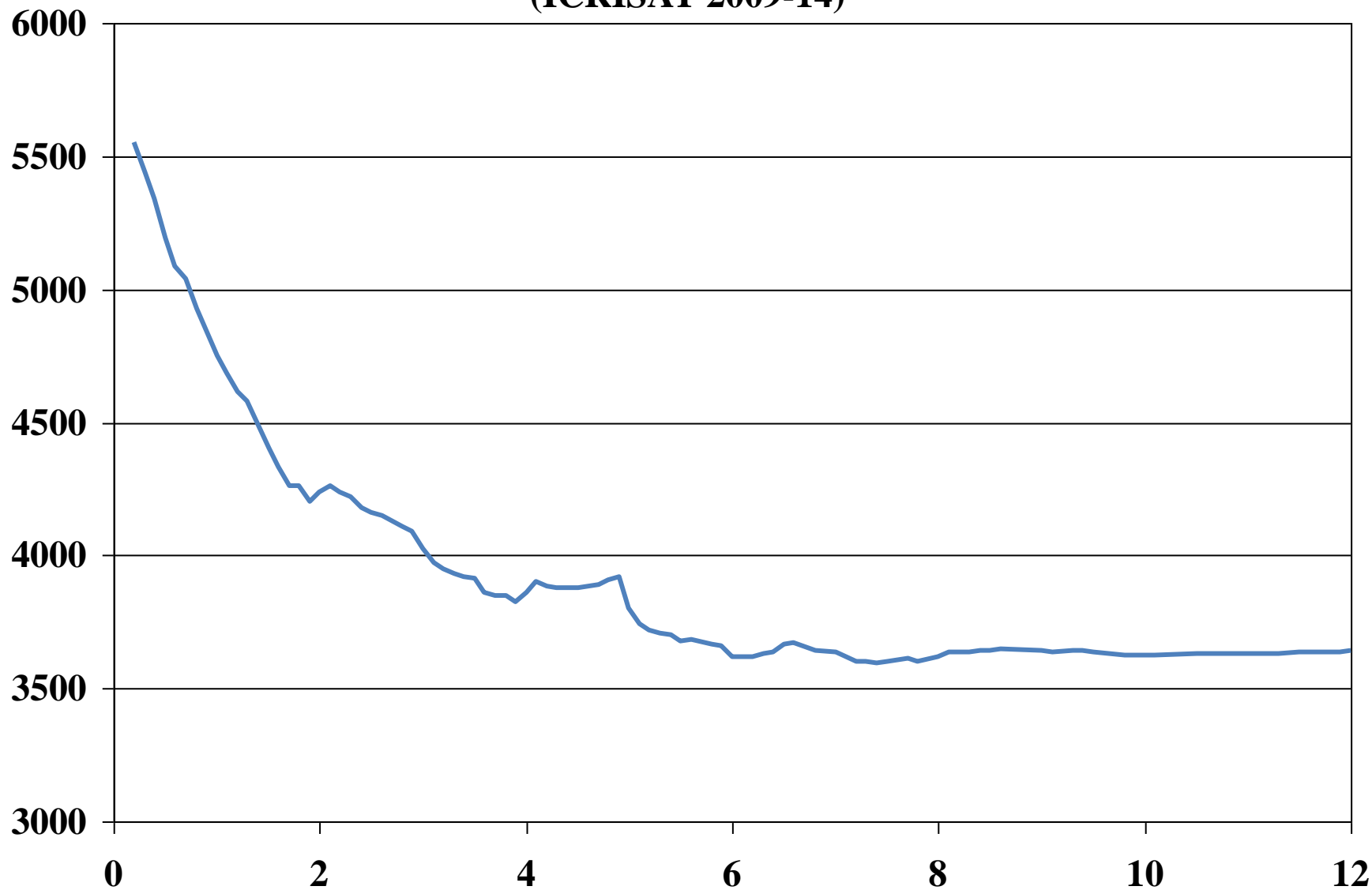
Market input price schedules (workers, machines, bullocks) by quantity of work time and by machine capacity.

Information on how plots were acquired (inheritance date if inherited (almost all)).

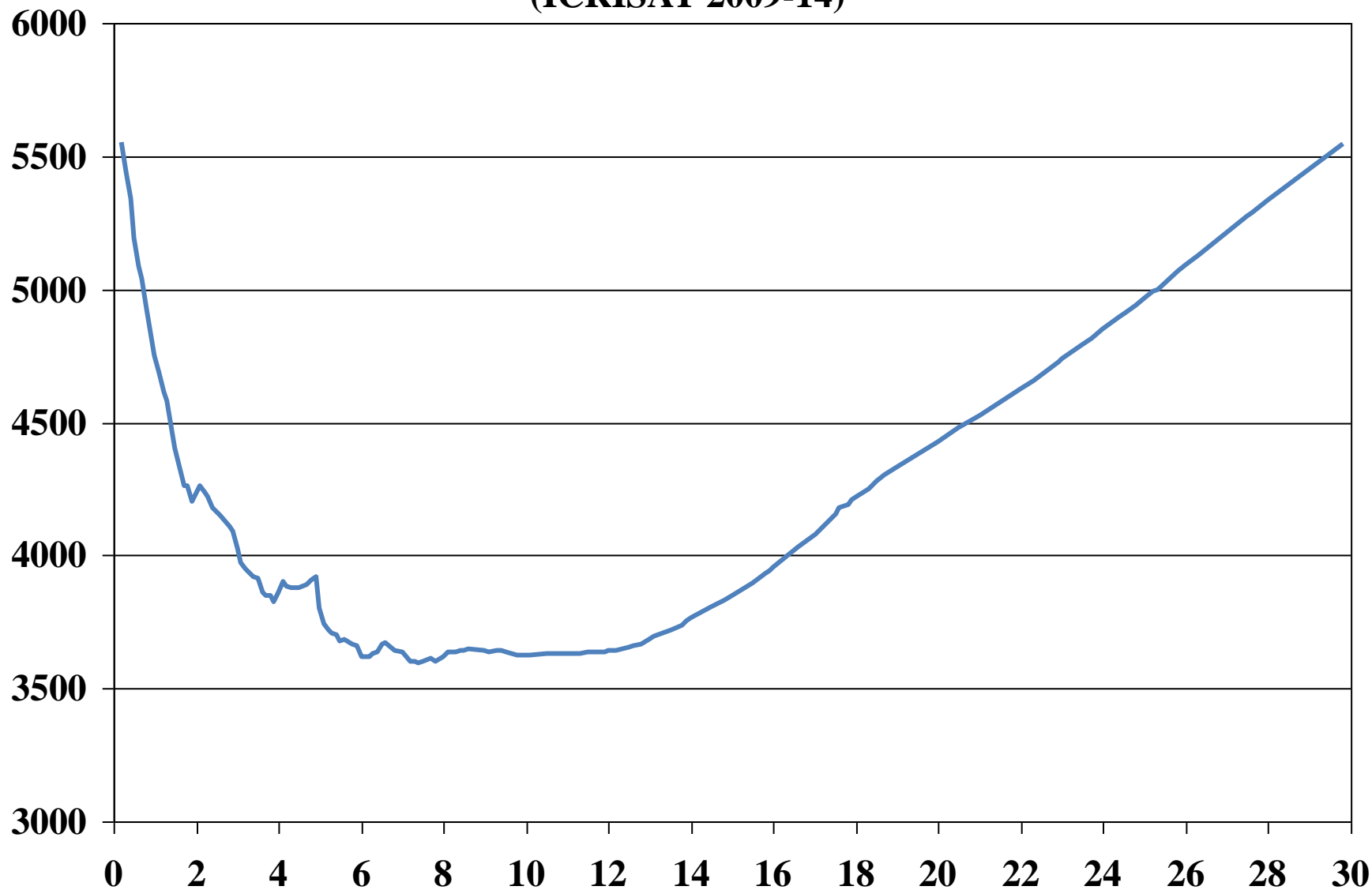
Complete inventories of owned assets, values and quantities.

Direct information on the capacities - productivity - of some individual farm machinery used in production.

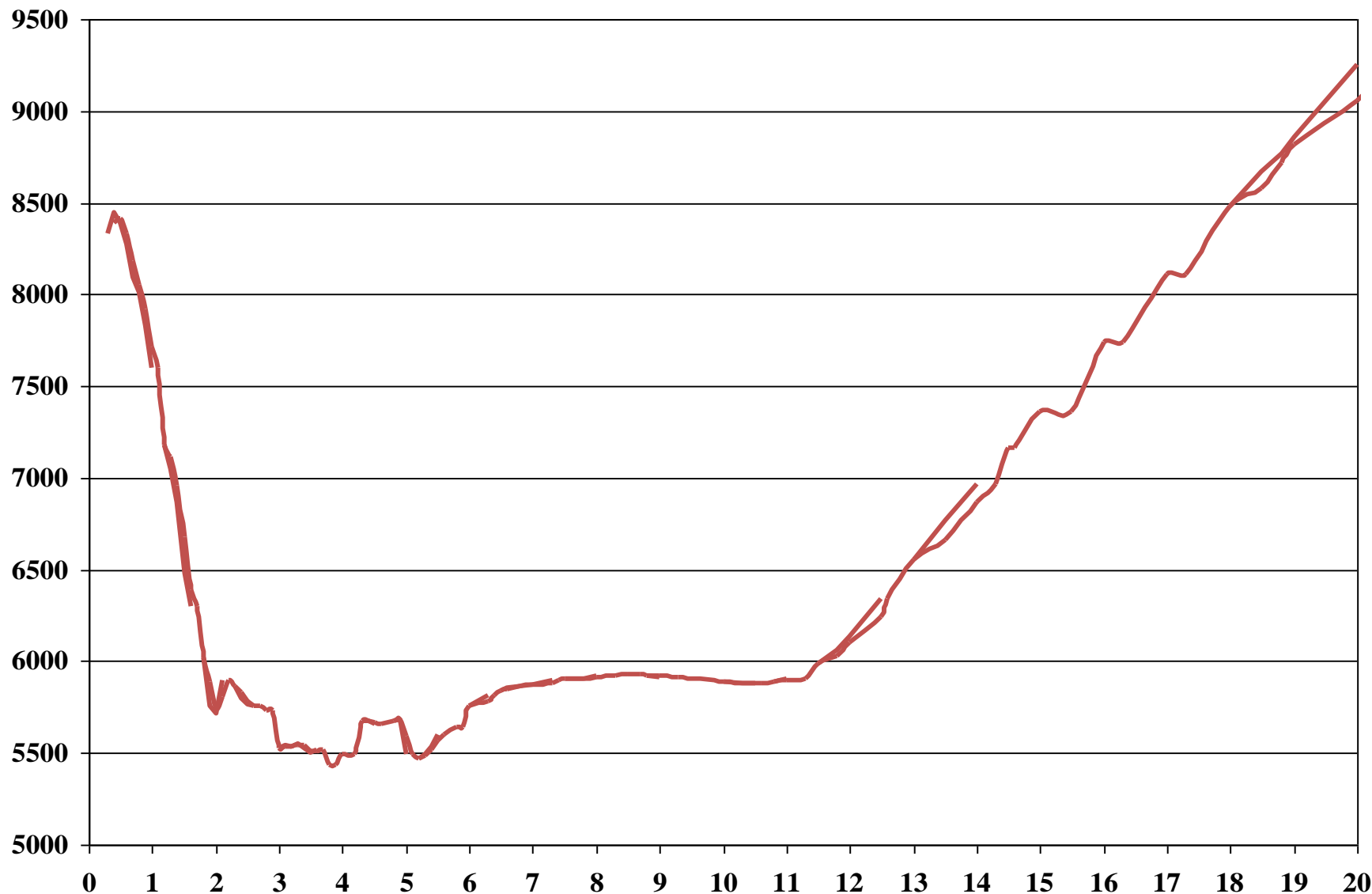
**Relationship Between Real Average Profits per Acre and Farm Size: 0.1-12 Acres
(ICRISAT 2009-14)**



**Relationship Between Real Average Profits per Acre and Farm Size: 0.1-30 Actres
(ICRISAT 2009-14)**



Cotton Plots: Lowess-Smoothed Relationship of Profits per Acre and Owned Plot Size (ICRISAT Survey, 2009-14)



Land Quality, Credit Constraints, Farmer Ability

Ruled out:

1. Test for measurement error using two independent measures of plot and land size, from the Census and the survey. Small and unrelated to scale.
2. 24 measures of plot characteristics, and we will carry out some plot fixed-effects tests.
3. U-shape is observed across plots *for the same farmer*:

Holds fixed ability and wealth.

So, the U-shape in profitability by scale is real.

What about land quality differences by size?

Have information at the plot level on:

Soil depth (continuous)

Soil fertility - 4 categories

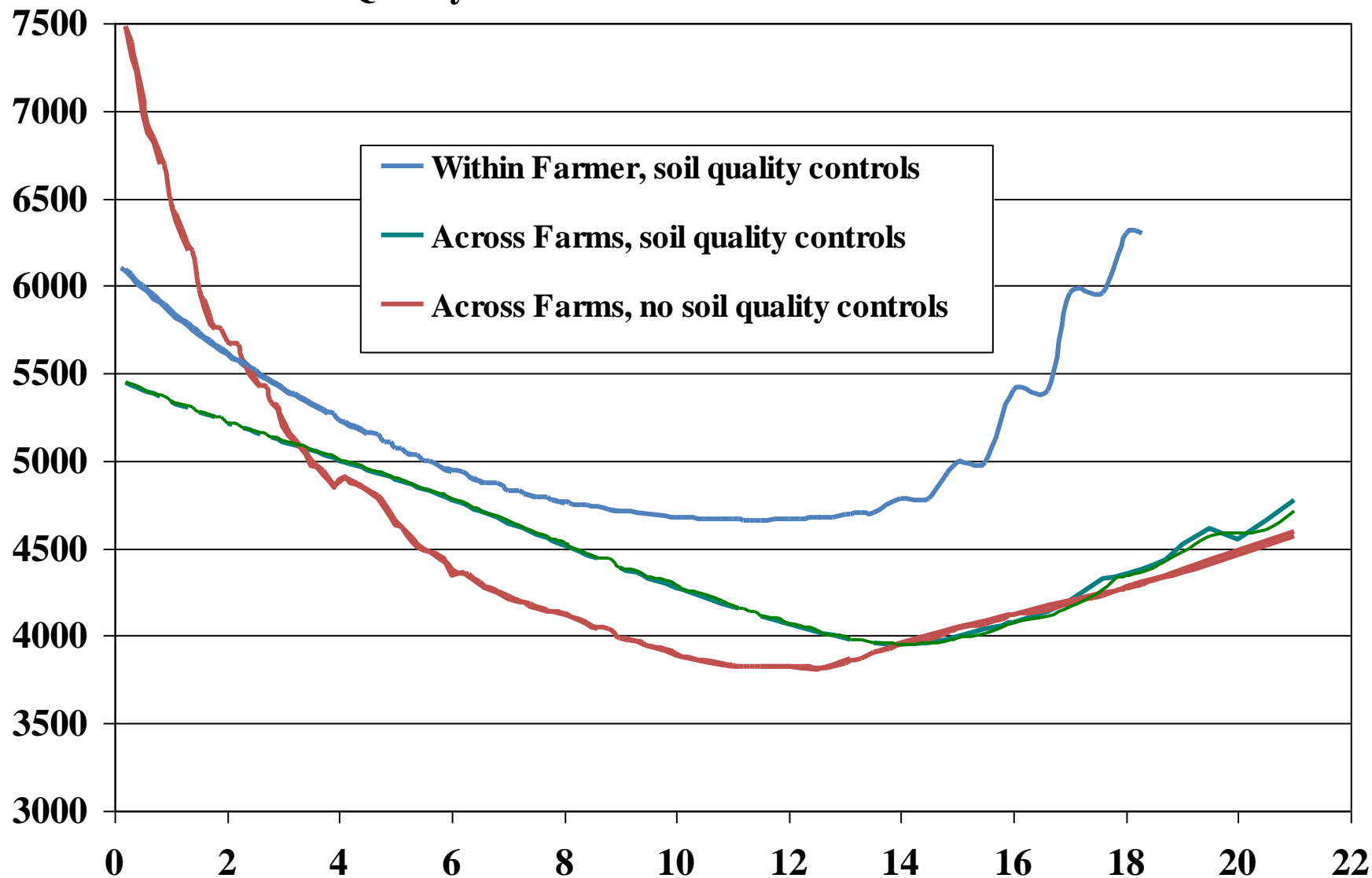
Soil degradation - 6 levels

Soil type - 11 types

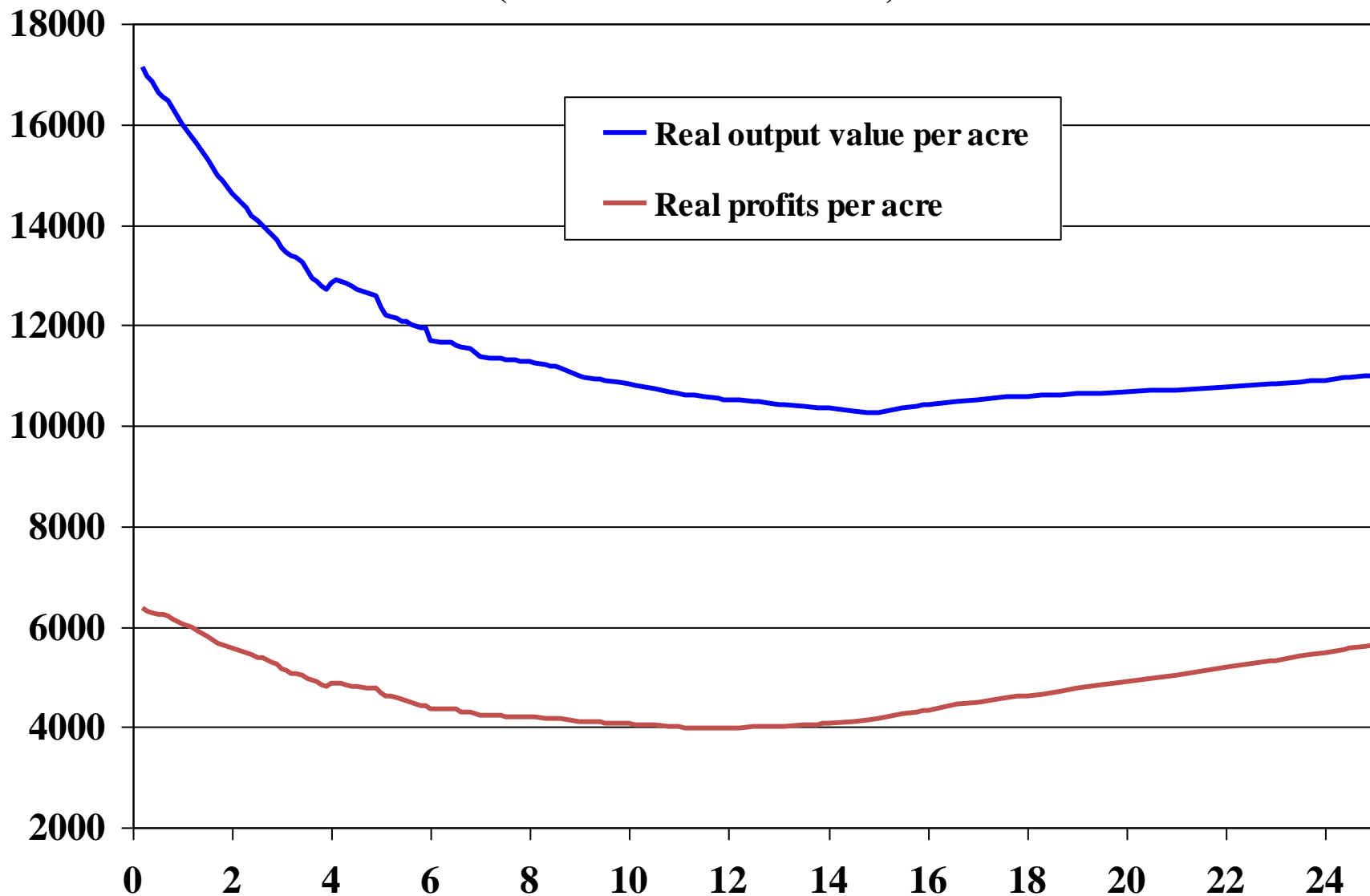
Distance from the house (continuous)

Location inside or outside the village

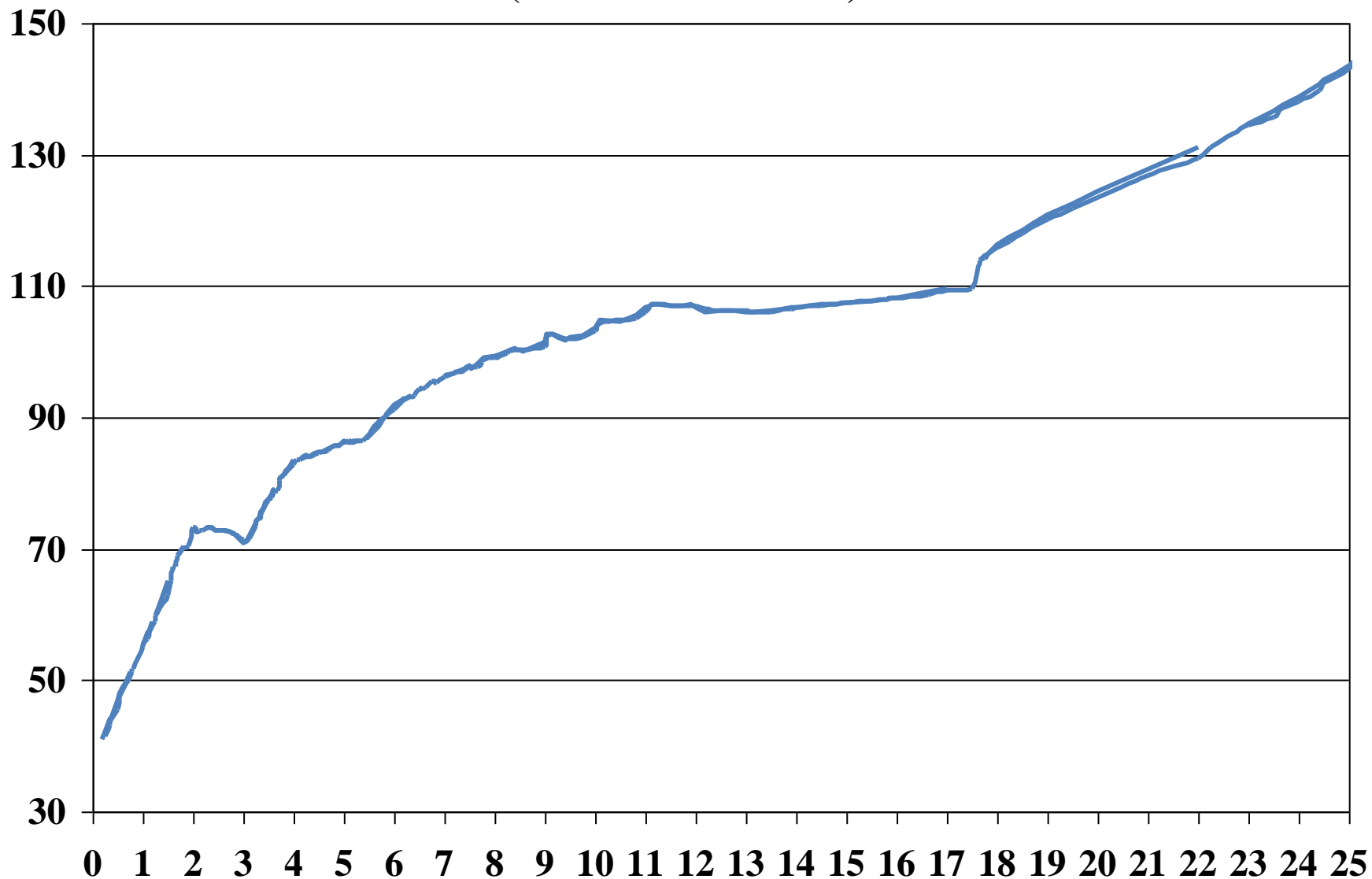
**Real Profits per Acre, by Owned Area,
Roles of Plot Quality and Farmer Characteristics: ICRISAT 2009-14**



**(Lowess-Smoothed) Real Output Value and Real Profits per Acre, by Scale
(ICRISAT VLS 2009-14)**



Real Output Per Worker Hour, by Farm Size (ICRISAT 2009-2014)



Plots and Farms

Plots are the basic spatial unit of production and are not choice variables.

1. In 2009, 85% of all owned land was inherited land, with no difference in origin for large and small landholdings.
2. Only 0.74% of all plot observations from 2009-2014 involved a purchase of land, the rest was inheritance/family transfer.
3. Plot size does not vary from year to year, but what is planted might.

43% of ICRISAT sampled farmers own one plot.

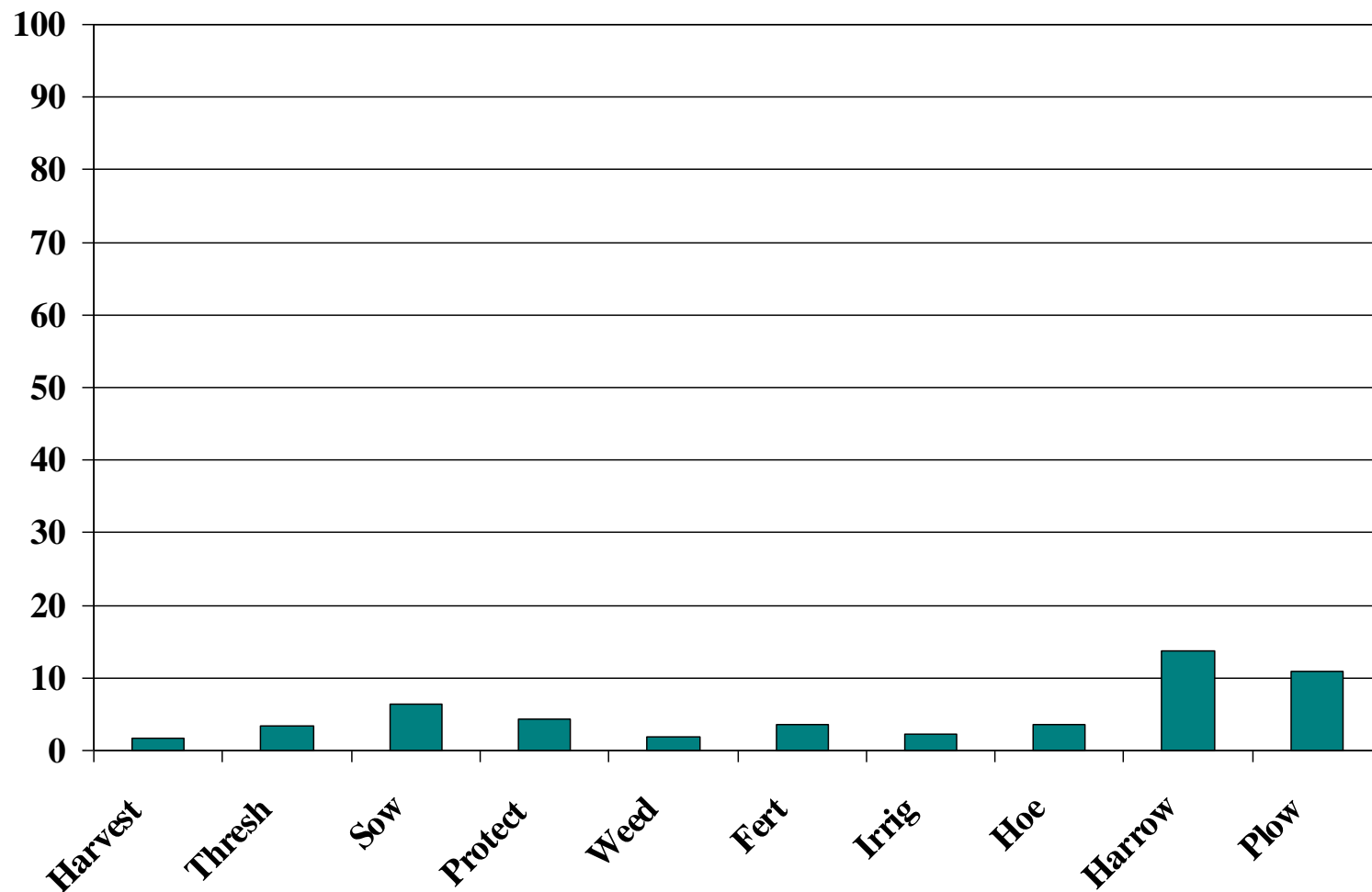
The timing of operations across plot for the same farmer is not perfectly synchronized, so scale economies are also plot-specific.

Based on the dates (day) of operation initiations, we find that the variance in operation start times is nearly as great across farmers in the same village as among plots for the same farmer.

Thus, we consider plot size as exogenous and estimates of farm scale and plot scale will be similar, net of unobservables.

The correlation between plot size and farm size even among those farmers with multiple plots is 0.7.

Percent of Operations Starting on the Same Day Across Farmer Plots, by Operation: Farmers with Two or More Plots in 2014



Can we explain the patterns we see?

Model that incorporates:

1. Fixed, transaction costs of hiring labor.

Travel, search (equipment? no)

Results in: falling average hourly wages with hours
 hired and thus with plot/farm size.
 autarchic farming

2. Economies of scale in equipment - price and capacity

Larger equipment more efficient than smaller units
in terms of processed acreage per hour.

Labor Market Transaction Costs

A. Laborers are hired on a daily basis for specific operations.

No long-term contracts = high search costs+ travel.

Yale EGC Tamil Nadu data: in *kharif*, laborers work on average for seven different farmers.

B. Travel costs:

Average distance between plot and homestead = 1 kilometer.

Workers and farmers live in village center.



Shirpur

Maharashtra Village



Imagery ©2017 CNES / Airbus, DigitalGlobe, Map data ©2017 Google United States 1 mi

The labor market extends beyond the village.

Tamil Nadu Survey (200 villages):

23.6% of laborers report working for a farmer located outside the village.

21.3% of farmers in the village who employed wage laborers hired laborers from outside the village.

Among those workers (63.8%) traveling by foot or bicycle to a non-village farm, average distance was 2 kilometers.

Among those traveling by bus, the average distance was 8 kilometers.

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

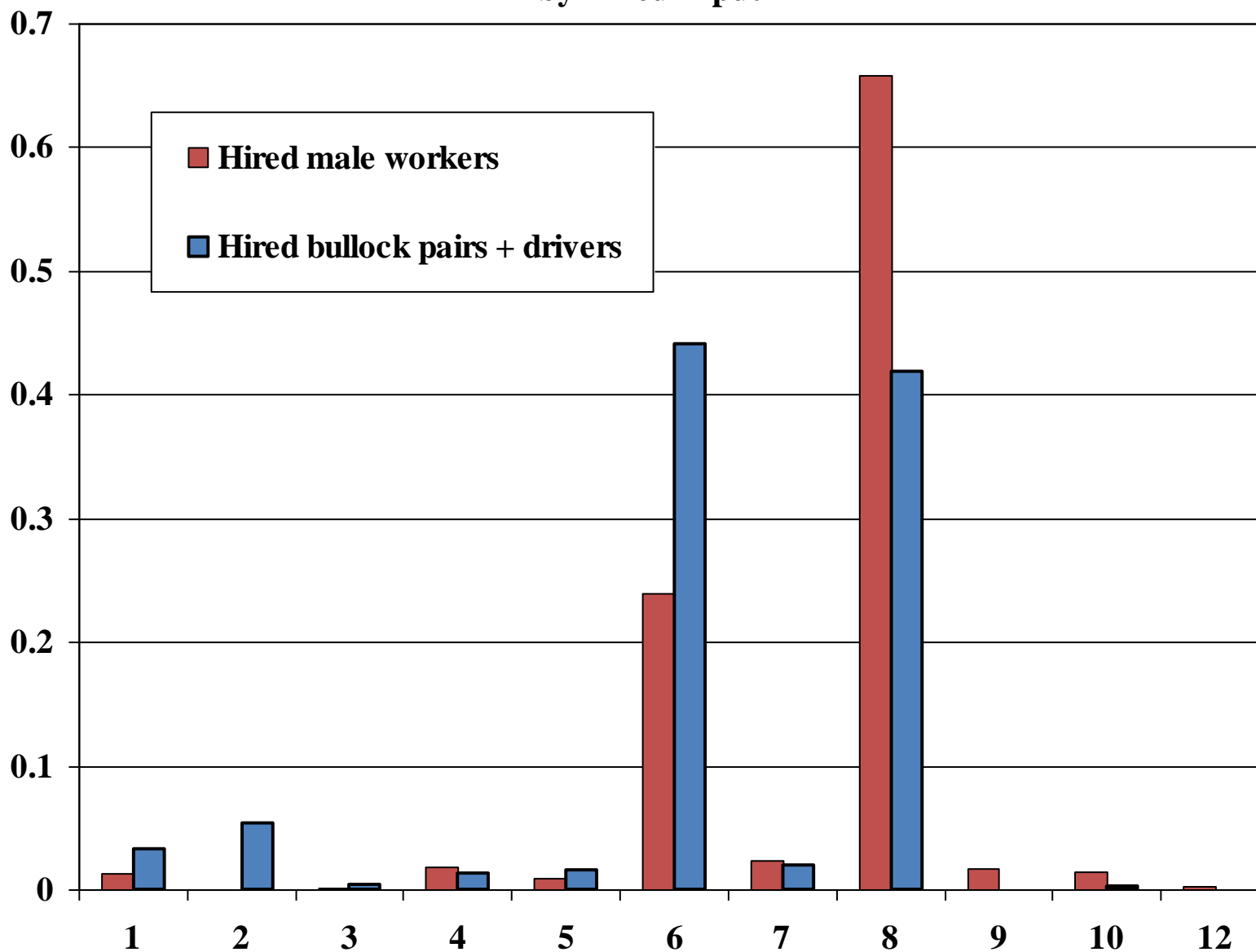


Table 1
Operation Fixed Effects Estimates: Percent Difference in Hourly Wage Rates Paid
for Eight Hours versus Less than Eight Hours of Work, by Input and Data Source

Input	Hired Male Labor		Hired Bullock Pair + Driver		Sprayer
Data source	2010, 2011 Monthly Price Schedules	2014 Input Survey	2010, 2011 Monthly Price Schedules	2014 Input Survey	2009-2014 Input Surveys ^b
Worked eight hours in the day versus <8	-33.2 (3.14)	-34.7 ^a (11.9)	-22.3 (4.54)	-30.0 ^a (8.42)	-13.2 ^a (13.1)
Log capacity	-	-	-	-	0.626 ^a (0.128)
Mean wage (rupees)	22.1 (9.34)	34.7 (19.3)	78.7 (39.6)	114.2 (35.0)	15.9 (23.3)
Percent working <8 hours	30.7	44.4	58.4	61.0	19.3
N	729	3,387	450	1,240	1,201

^aFE-IV estimate; first-stage includes log of owned area and all land quality characteristics.

^bSpecification also includes village-year fixed-effects.

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

Hourly wage rate = daily wage/hours worked. Sprayer capacity = material sprayed per hour of use.

Table 2
FE-IV Estimates: the Percentage Hourly Cost Discount by Plot Area and Plot Distance from the Homestead,
for Male Hired Workers and Rented Sprayers^a
Dependent Variable=Log Hourly Wage/Rental Price

Input	Hired Male Labor (2014)		Sprayer (2009-2014)	
Worked eight hours in the day versus <8	-12.6 (12.7)	-6.21 (12.6)	-7.59 (14.4)	-2.02 (2.20)
Worked eight hours in the day*plot area	-31.2 (6.84)	-32.0 (6.98)	-4.86 (4.91)	-6.28 (5.04)
Worked eight hours in the day*plot distance from the homestead	-	-13.5 (2.78)	-	-11.1 (12.1)
Log capacity	-	-	0.582 (0.135)	0.423 (0.139)
Operation fixed effects	Y	Y	N	N
Village-year fixed effects	N	N	Y	Y
N	3,387		1,201	

^aFirst-stage includes owned area and all land quality characteristics.
Standard errors in parentheses clustered at the village-year level.
Sprayer capacity = material sprayed per hour of use.

The hourly wage estimates are consistent with the existence of fixed hiring costs.

Workers entering the labor market for off-farm work 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 total cost of hiring a worker for l_{h1} hours is

$$(1) \quad w(l_{h1}) = w_0 + w_1 l_{h1} .$$

w_1 = marginal hourly wage, w_0 = fixed compensation paid

Calculation of fixed costs w_0 from (1).

We need the distribution of hours worked by part/full time to compute the fixed costs.

Let f_i^p = the fraction of part-time workers working l_{hi}^p hours, then the average wage for part- time work (<8) given (1) is

$$\bar{w}^p = \sum_{i=1}^7 \left(\frac{w_0 + w_1 l_{hi}^p}{l_{hi}^p} \right) f_i^p$$

and, similarly, the average wage for full-time work (8-12 hours) is

$$\bar{w}^f = \sum_{l=8}^{12} \left(\frac{w_0 + w_1 l_{hi}^f}{l_{hi}^f} \right) f_i^f .$$

Table 1 tells us that $\bar{w}^p = 1.347\bar{w}^f$.

Substituting, with $w_1=21$ from the wage schedules.

w_1 = the change in daily earning of an extra hour of work when working > 8 hours.

Yields an estimate of the fixed cost $w_0 = 178$ Rs paid per worker.

Thus, transaction costs = $178/(21*8 + 178) = 51.1\%$ of the daily wage.

The Model

A. First, labor only, with transaction costs.

The relevant unit is the operation: provide nutrients.

Simple, one operation model, extended to more.

Sufficient to get U-shape, but not continuing scale economies at high scale (implies most productive farms are the smallest).

B. Add machinery heterogeneous in capacity.

Generate U-shape with continuous rise in productivity after a threshold.

To fix ideas we work with a one-task, one-period agricultural CRS production technology g in which the fundamental inputs are endowed land a and nutrition e .

Total output is thus given by

$$g(a, e)$$

To begin, we assume that plant nutrition production is a function of labor only:

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

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

For costing labor, consistent with (1), we need to also take into account the hiring of multiple workers.

Suppose each worker is only willing to work at most l_{mx} hours (8?).

From (1), the cost of hiring l_h hours of work on a given day when each worker works only up to l_{mx} hours is

$$(3) \quad w_h(l_h) = \text{ceil}(l_h / l_{mx}) w_0 + w_1 l_h .$$

where $\text{ceil}()$ is the ceiling function:

A farmer must pay: $w_0 + 4w_1$ for 4 hours of work

$2w_0 + 11w_1$ for 11 hours if $11 > l_{mx}$.

What is the opportunity cost of applying l_f hours of family labor on the farm?

Equation (3) also characterizes the wage income for off-farm work by family members.

Accounting for the entry cost, f , the opportunity cost is

$$(4) \quad w_f(l_f) = \text{floor}(l_f / l_{mx})(w_0 - f) + w_1 l_f$$

Note: if $w_0 = f$ workers are fully compensated for the fixed costs of off-farm work.

Assume for now that is true - we estimate separately f and w_0 in the calibrated full model

Farm profits π are thus

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

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

The farmer's programming problem:

$$\max \mathcal{L} = \pi(a, l_{h1}, l_{f1}) + (w_0 - f) + w_1 l_o$$

subject to the constraint $l_o + l_f = l$, where l_o = off-farm work.

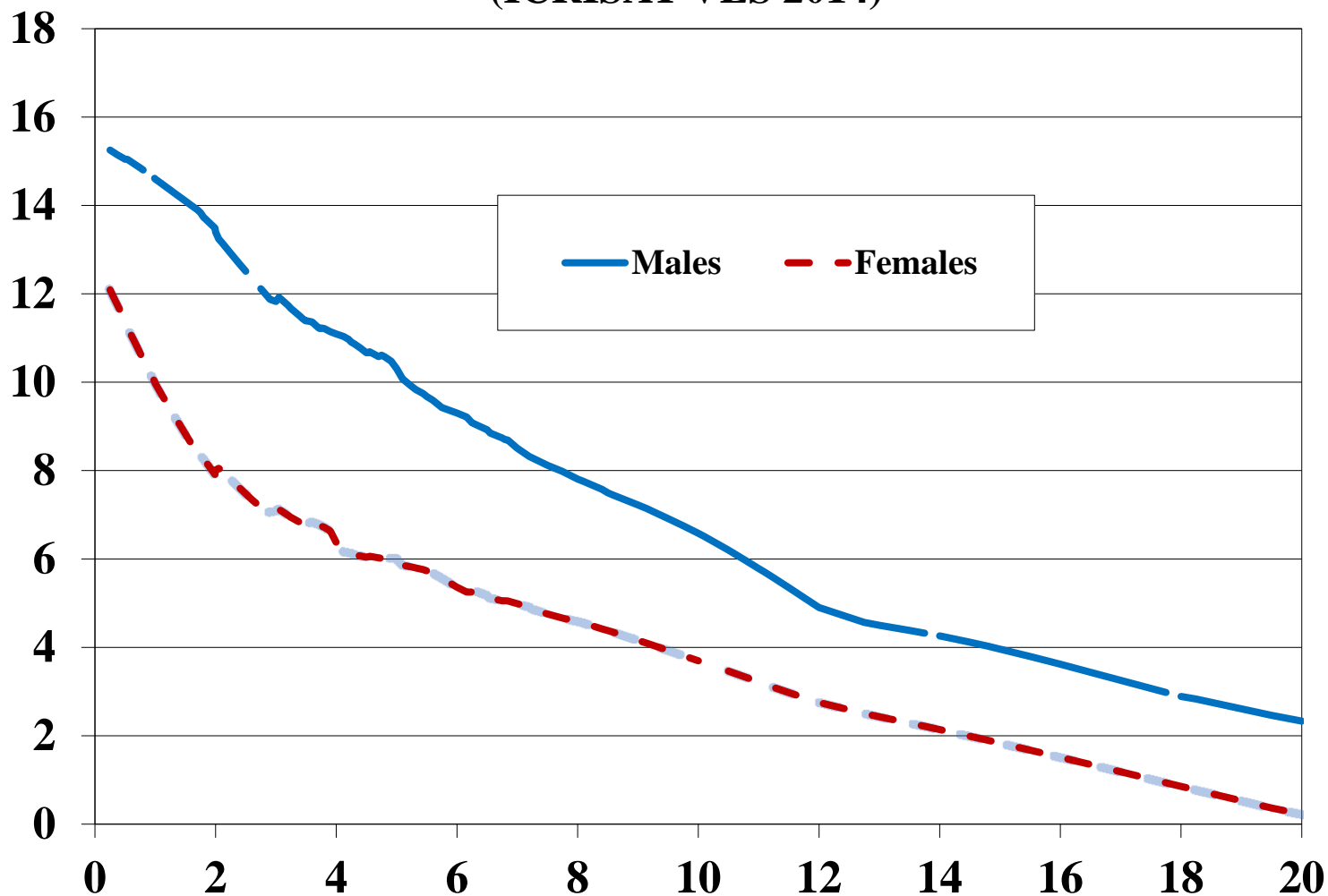
Given the labor transaction cost, there will be three regimes characterizing the use of family and hired labor with two land thresholds determined by the magnitude of f .

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

At the lowest 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 employing all family workers full time on the farm and some entering the labor market.

Average Days per Month Worked Off Farm, by Farm Size
Male and Females Aged 21-59
(ICRISAT VLS 2014)



At that upper bound:

$$g(a^*, l) = g(a^*, l_f^*) + (w_0 - f) + w_1(l - l_f^*),$$

and at all land sizes $< a^*$

$$f_l(a^*, l_f^*) = w_1.$$

Thus, if all farms $a < a^*$, labor would be allocated efficiently in the economy (all hiring of labor in non-farm enterprises).

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

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

Because of the transaction costs, this is a non-trivial regime.

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

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

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

Until that upper limit, from a^* :

As acreage increases, up to a^{**} , average profitability declines, given the fixity of the family labor force.

Labor per acre also declines with acreage.

Labor is allocated inefficiently across autarchic farms, (differing marginal products).

Labor is under-utilized in autarchic farms:

$$f_l(a^*, l_f^*) > w_1.$$

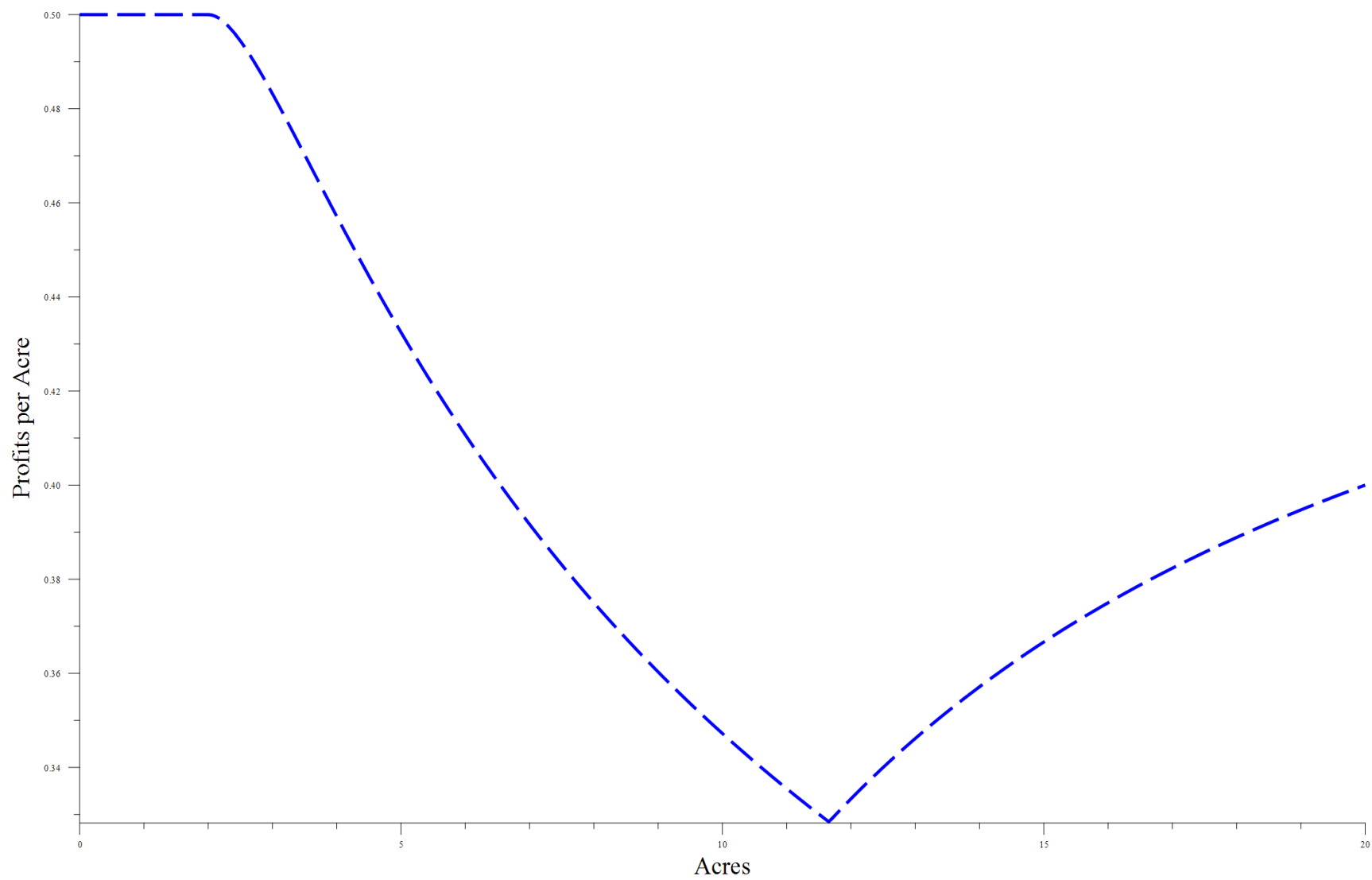
Regime 3 ($a > a^{**}$): Farmers work on farm and hire workers.

We simulate the model, assuming Cobb-Douglas technology with a labor share of 0.5, $w_0=2$, $w_1=0.5$, $f=2$, $l=2$.

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:

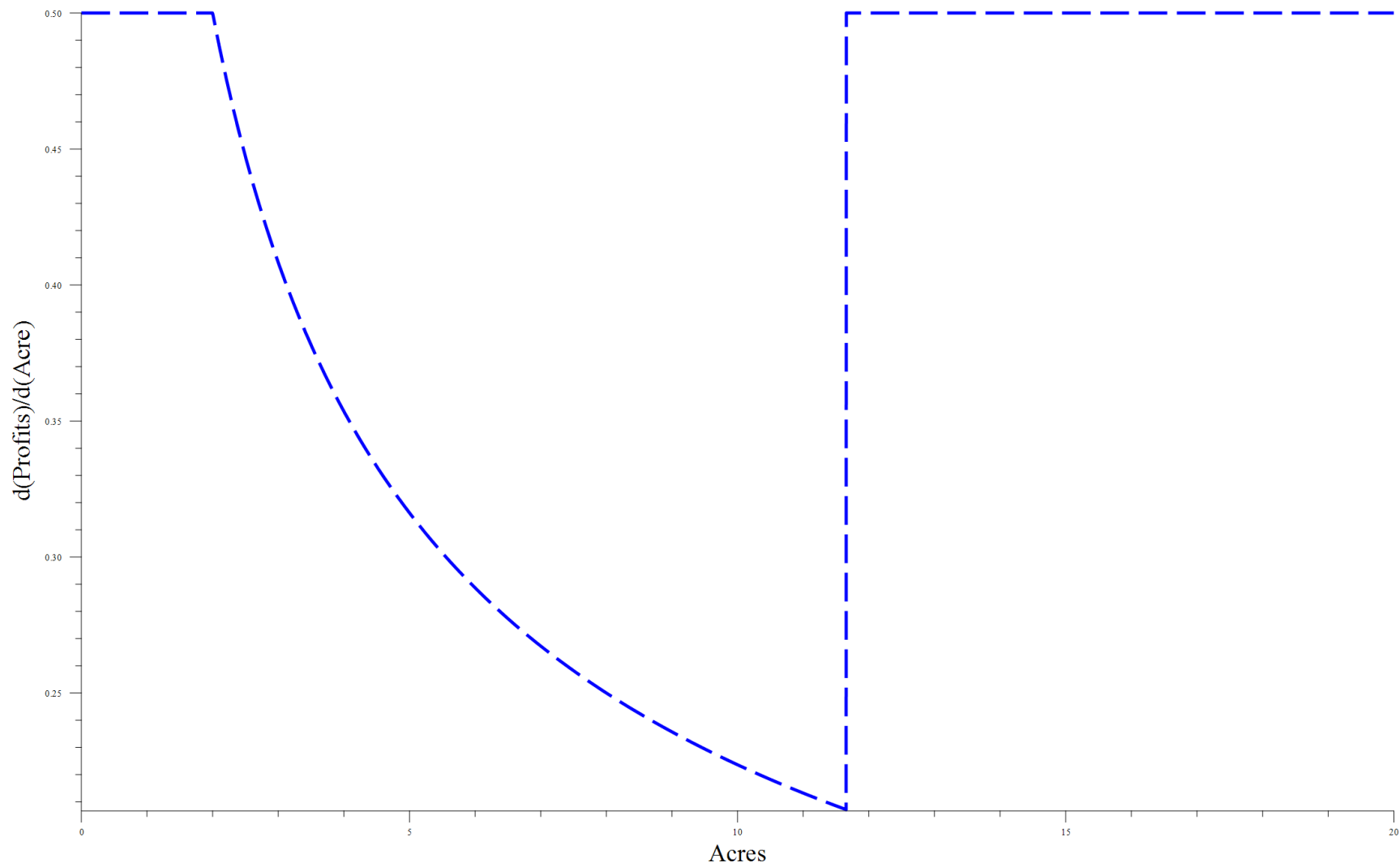
On small farms, workers are working off farm and thus changes in acreage have no effect on profits per acre.

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.

Average profitability then rises with acreage as the fixed cost component becomes a decreasing share of total labor costs.

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



Adding *Heterogeneous* Machinery

The labor-only model with fixed market costs can explain the U-shape for average profits.

However, it is clearly inadequate for explaining how average profitability could ever be higher than that of the smallest farms.

This is because average profitability reaches its maximum when the fixed cost component becomes an epsilon share of total labor costs. And that is always zero for the smallest farms.

We now add the possibility of employing machinery, which can substitute for labor and is heterogeneous in capacity.

A key distinction for machinery: time and effective capacity q

q = amount of processed acreage per unit of time

Effective capacity depends on both the machine and farm size:

An 8-row harvester will not process any more acreage on a 4-row farm compared with a 4-row harvester.

A power sprayer that can cover a radius of x yards would be no more effective than a weaker sprayer on farms where the radii of farmed area are significantly less than x .

So $q = \phi(a)$, with $\phi'(a) > 0$.

Obviously, labor is heterogeneous too, but differences in *manual* agricultural labor within gender are sufficiently small as to not be reflected in time wages (Foster and Rosenzweig, 1993(!)).

Farm machinery comes in different capacities, which are priced differentially.

We assume that the rental cost of per unit of time r_m of a machine of capacity q is

$$r_m = p_q q^v$$

Thus the machine cost per-time-unit rises with capacity, but at a declining rate if $0 < v < 1$. This is key.

The farmer chooses the capacity of the machine q and how much time m to employ it based on both acreage and price.

To capture these ideas we redefine the nutrient production function as

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

where q = machine capacity, m = the number of units of time the machine is employed.

ξ captures output per hour of work, δ captures the extent of substitutability of labor and machines.

We assume that operation of the machinery requires θ of family labor per hour of machine operation.

The hourly cost of a machine inclusive of labor is thus

$$pq^{\vee} + w\theta .$$

Profits, augmented to include the use of farm machinery, are

$$\begin{aligned} \pi(a, l_h, l_f, q, m) = & g(a, e(l_h + l_f), q, m)) \\ & - w(l_h) - wl_f - (w\theta + p_q q^{\vee})m \end{aligned} .$$

In this model machine capacity is determined only by acreage and the machine price parameters.

In particular to minimize costs, q , solves

$$\frac{\theta w}{p} + [(1 - \nu) q^\nu \phi(a) - (2 - \nu) q^{\nu+1}] / (\phi(a) - 2q) = 0.$$

- A. Second-order conditions require that $\nu < 1$; the cost of capacity does not rise linearly - this is a key source of economies of scale.
- B. The cost-minimization expression is linear in the wage w and the base equipment price p .

Given the non-linear price schedule, we can show that machine capacity used increases with acreage, as long as effective capacity φ rises with acreage:

$$\frac{dq}{da} = \frac{q^2 \phi'(a)}{(\phi(a) - q)(\phi(a)\nu - 2q\nu - \phi(a) + 4q)}$$

And increases in wages also increase capacity:

$$\frac{dq}{dw} = \frac{\theta q (\phi(a) - 2q)^2}{pq^\nu \nu (\phi(a) - q)(\phi(a)\nu - 2q\nu - \phi(a) + 4q)} > 0$$

The key difference from the labor-only model is that average profits rise more rapidly with scale and reach a level higher than those of the smallest farms.

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

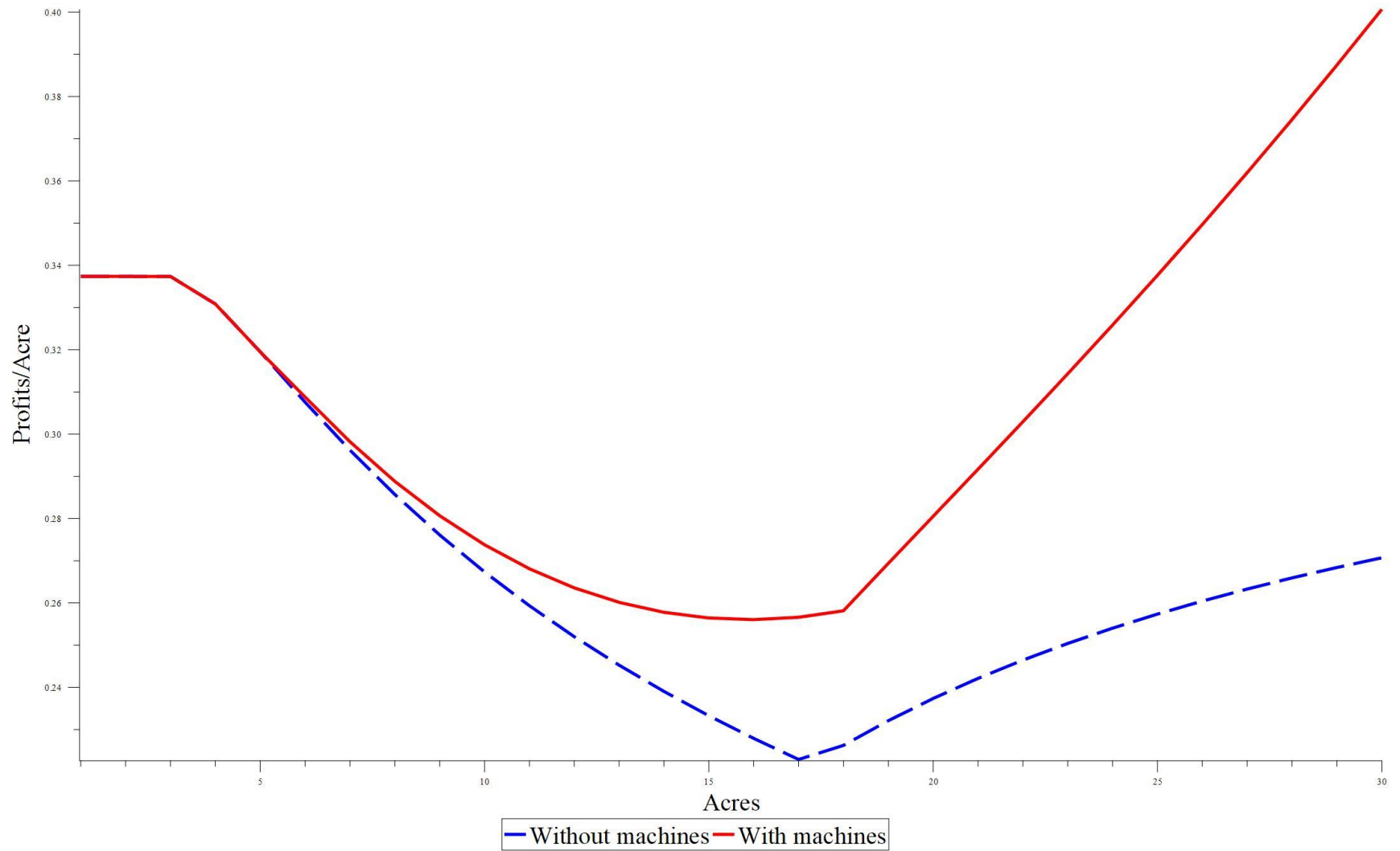
- Rise with farm size after 10 acres

- 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.

Can we identify these specific mechanisms in the data?

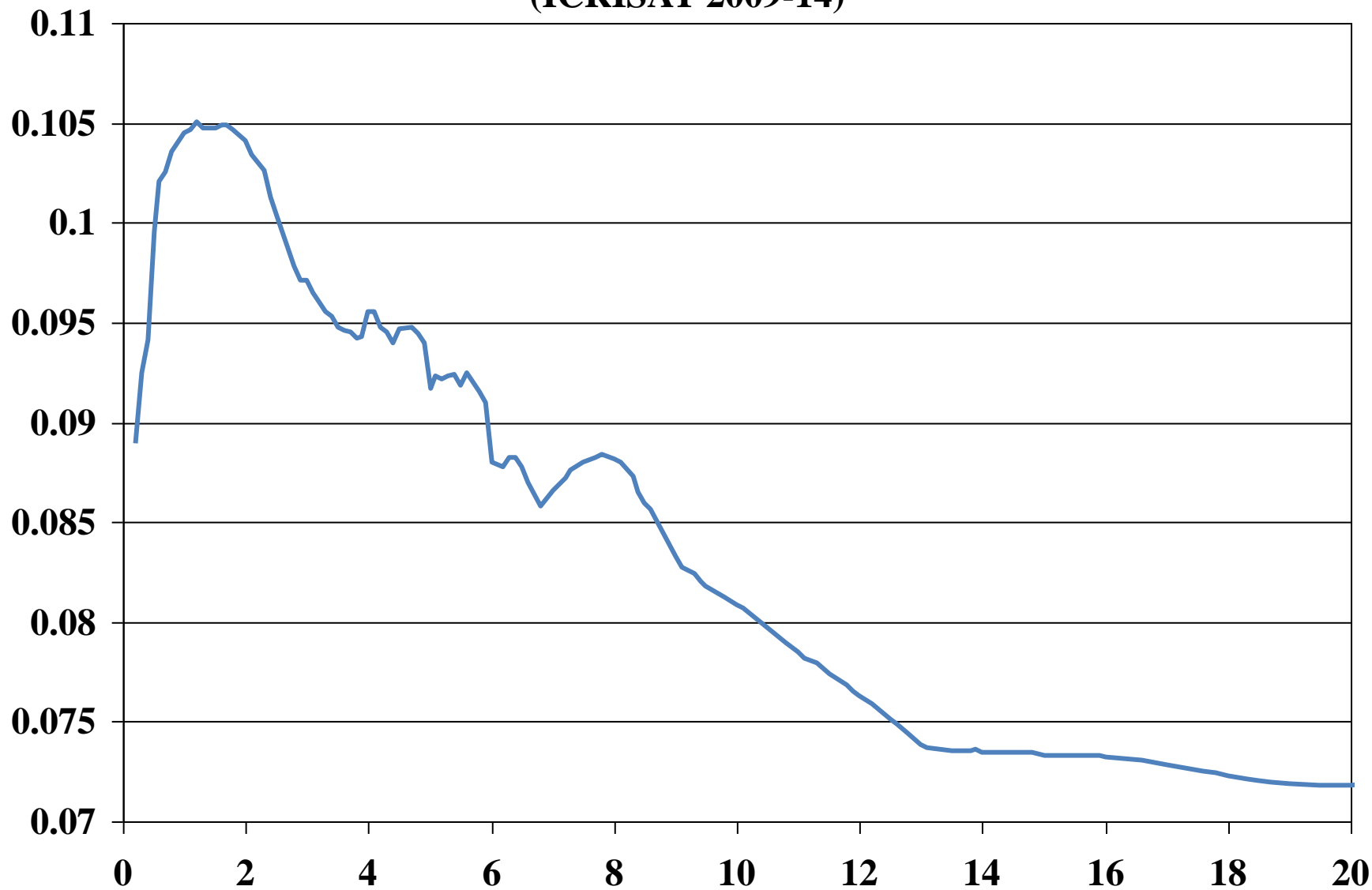
Figure 3: Average Profits and Land Size with and without Machinery



Tests for the mechanisms:

- 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 first raise and then lower low-hour input use and unit input costs? Yes.
- D. Do we see evidence of scale economies in the use of mechanized equipment? Yes.

**Mean Fraction of Operations Using Low-Hours Hired Male Labor, by Farm Size
(ICRISAT 2009-14)**



**Mean Real Wage Paid for Male Labor, by Farm Size
(ICRISAT 2009-14)**

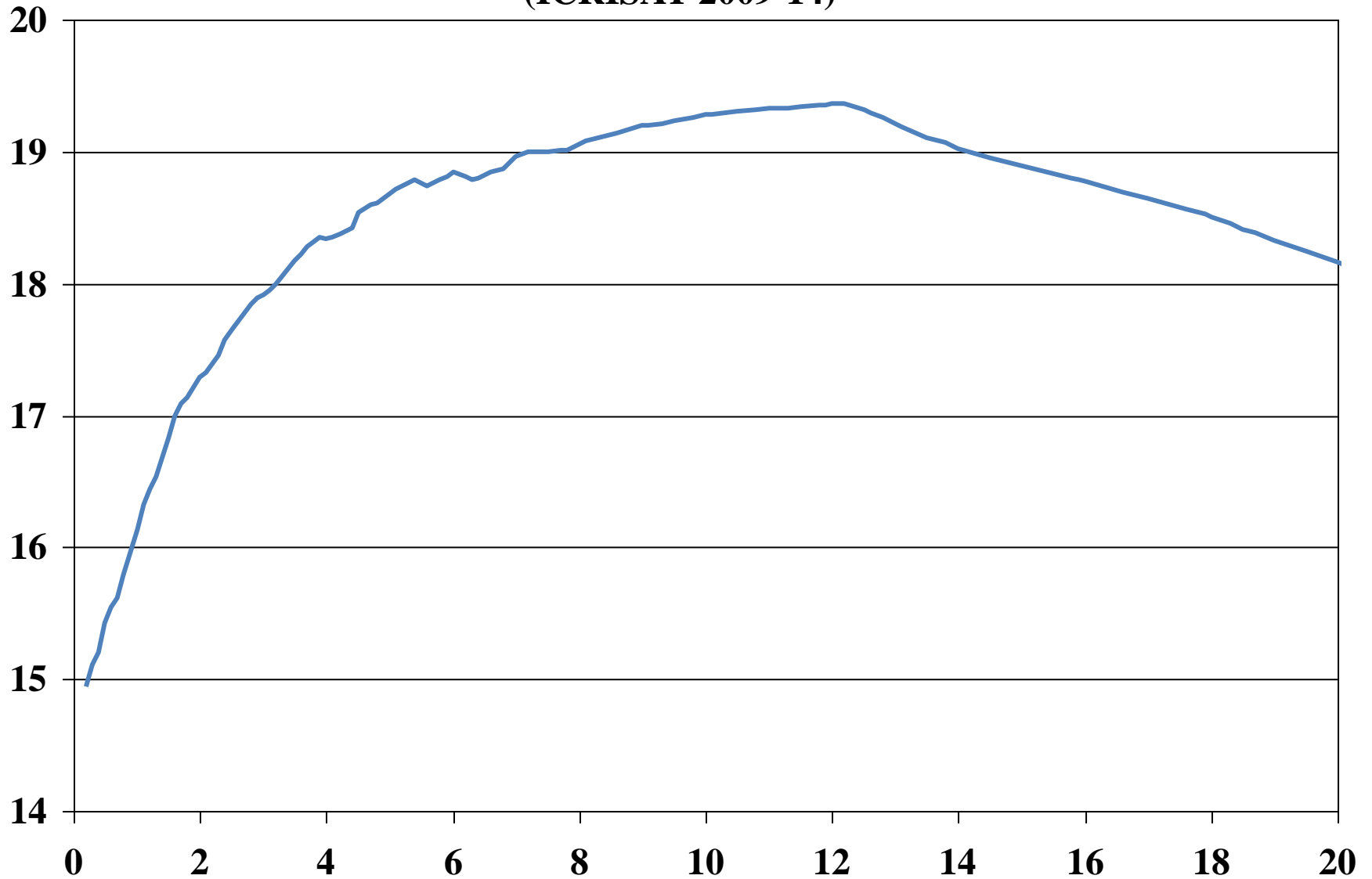


Table 5
Plot Size and Fraction of Operations that Employ Hired Inputs at Low (≤ 6) Daily Hours
and the Average Hourly Wage Paid,
by Input Type (*Kharif* Seasons 2009-14)

Variable	Fraction of Operations ≤ 6 Hours/Day			Average Hourly Wage		
	Hired Male Labor	Hired Tractor	Hired Bullock Pair	Hired Male Labor	Hired Tractor	Hired Bullock Pair
Plot size (acres)	-0.0165 (0.00306)	-0.0197 (0.00247)	-0.0170 (0.00306)	-0.183 (0.0876)	1.25 (0.769)	-0.866 (0.306)
Plot size squared $\times 10^{-3}$	0.450 (0.112)	0.449 (0.0682)	0.555 (0.117)	8.29 (3.23)	18.3 (32.4)	29.3 (10.9)
Village/year FE	Y	Y	Y	Y	Y	Y
Plot 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.

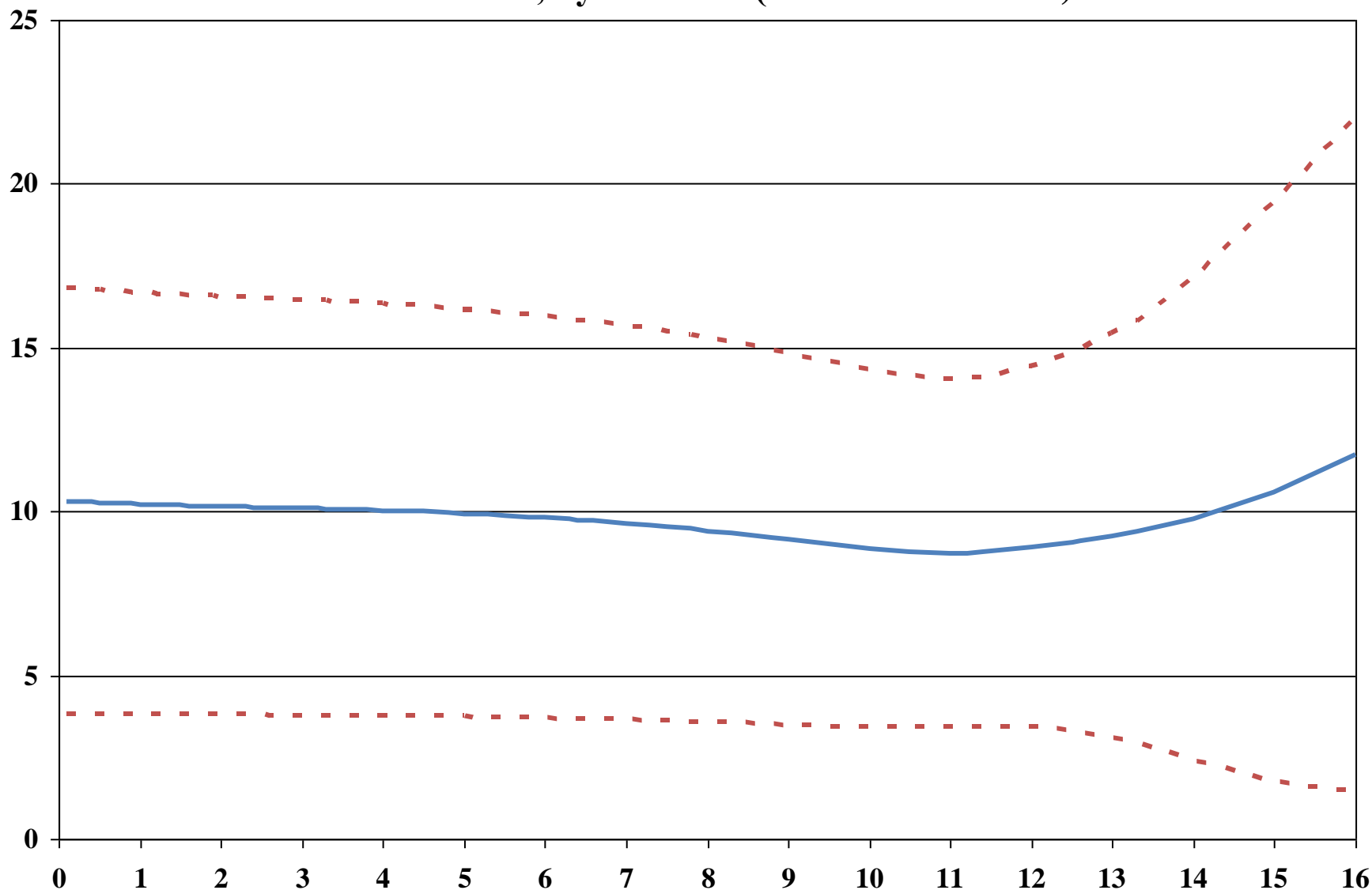
Table 6

Plot Fixed Effects Estimates: The Effects of *Kharif*-Season Rainfall on Profits, Hours Employed and Average Hourly Wage Rates, by Input Type (*Kharif* Seasons, 2009-14)

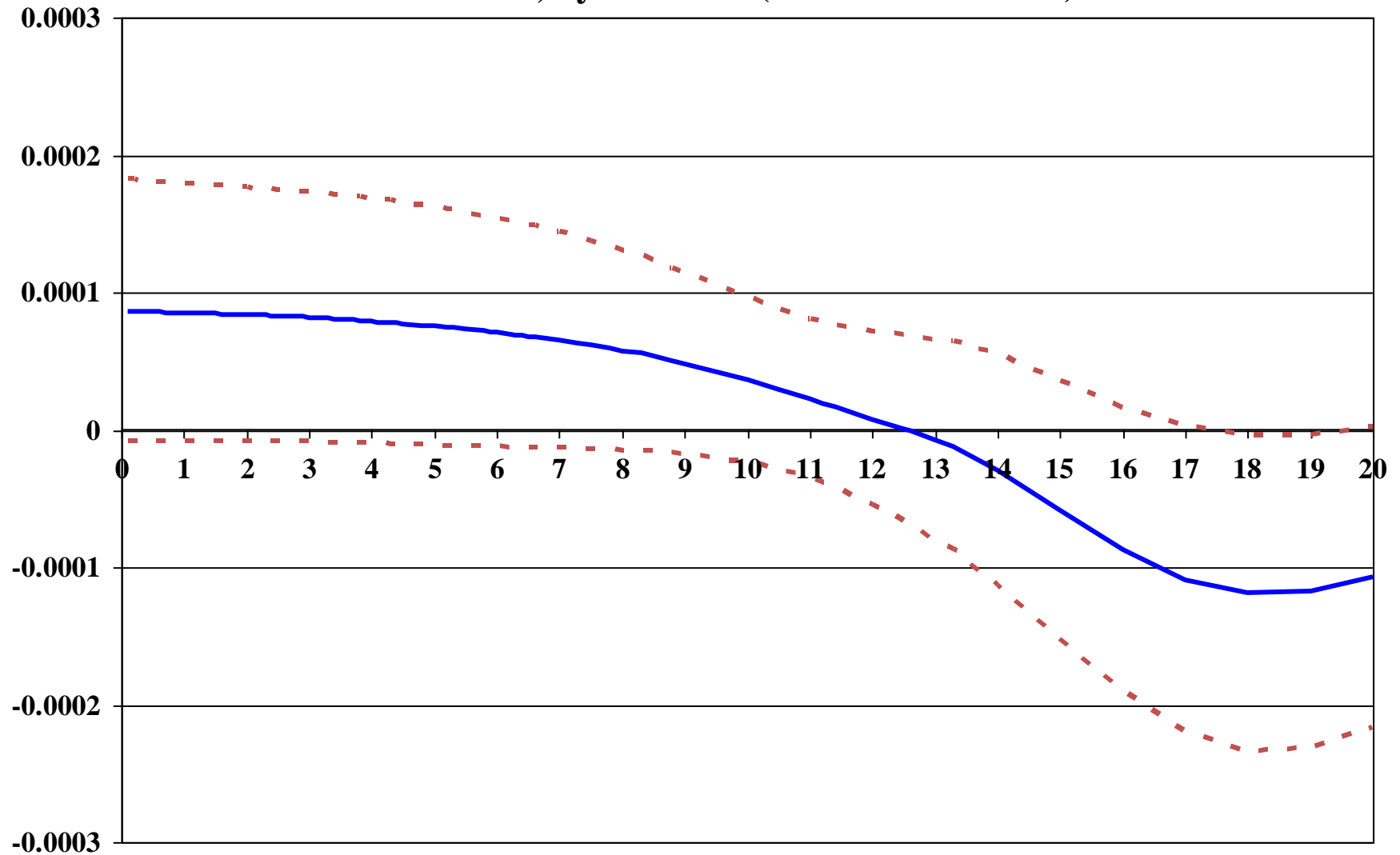
Variable	Profits	Hours Employed			Average Hourly Wage		
Input type	-	Hired Male Labor	Hired Tractor	Hired Bullock Pair	Hired Male Labor	Hired Tractor	Hired Bullock Pair
Rainfall (mm)	38.1 (17.1)	0.182 (0.0701)	0.00362 (0.00316)	0.0347 (0.0248)	-0.0158 (0.00672)	0.0130 (0.0601)	-0.0593 (0.0355)
Rainfall squared $\times 10^{-3}$	-21.2 (8.59)	-0.107 (0.0377)	-0.00214 (0.00161)	-0.0500 (0.0268)	0.00778 (0.00398)	-0.0132 (0.0282)	0.0757 (0.0331)
Year and plot FE	Y	Y	Y	Y	Y	Y	Y
H_0 : Rain and rain squared = 0 F [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.

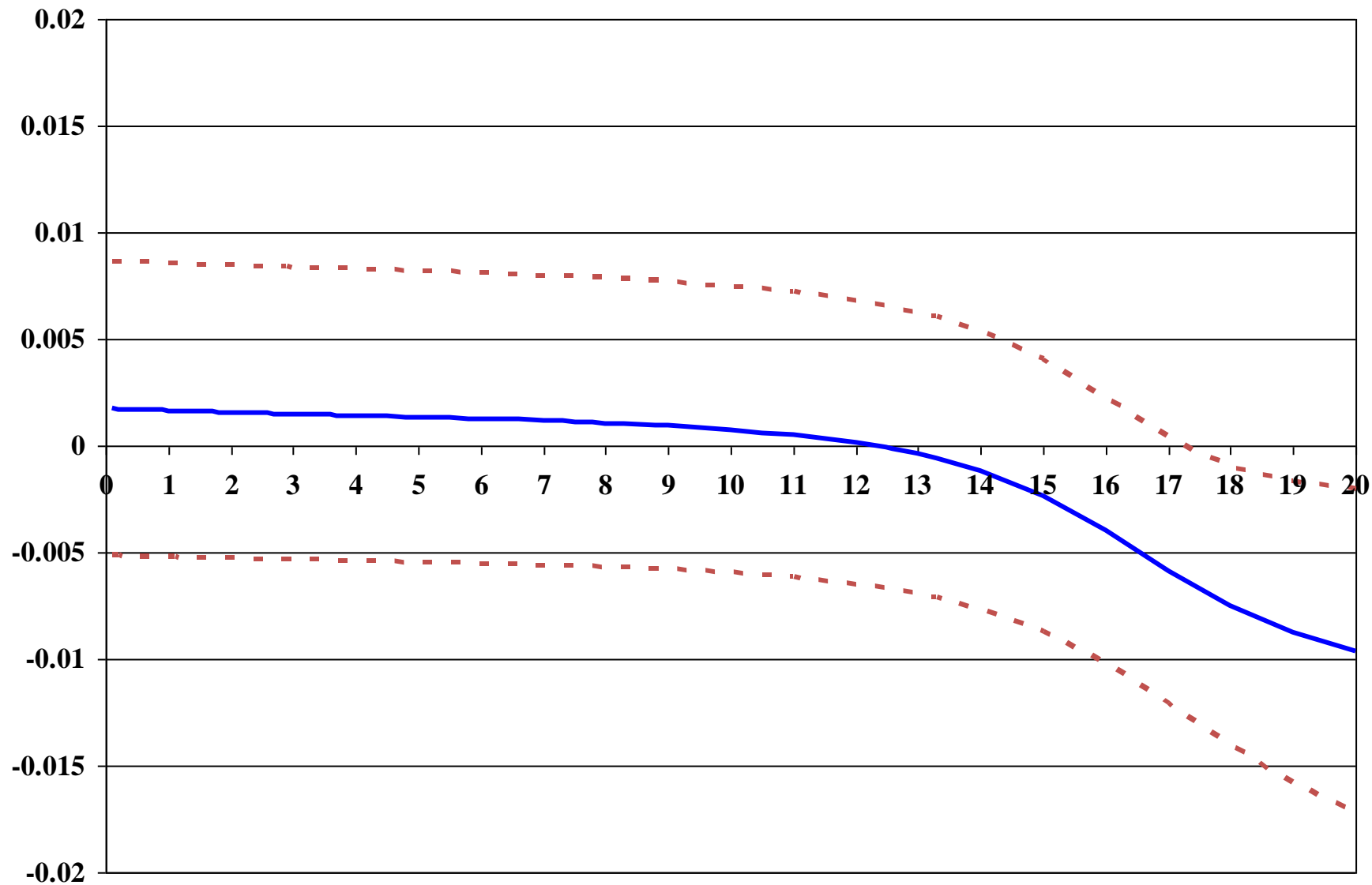
**LWFCM Plot Fixed-Effect Estimates of the Effects of Rainfall on Profits per Acre,
with 95% CI's, by Plot Size (ICRISAT 2009-14)**



**LWFCM Plot Fixed Effect Estimates:
The Effect of Rainfall on the Fraction of Operations Using Low-Hours Hired Male Labor,
with 95% CI, by Plot Size (ICRISAT 2009-14)**



**LWFCM Plot Fixed-Effect Estimates: the Effect of Rainfall on the Average Male Wage,
with 95% CI, by Plot Size (ICRISAT 2009-14)**



Weed Management, Sprayers and Equipment Scale Economies

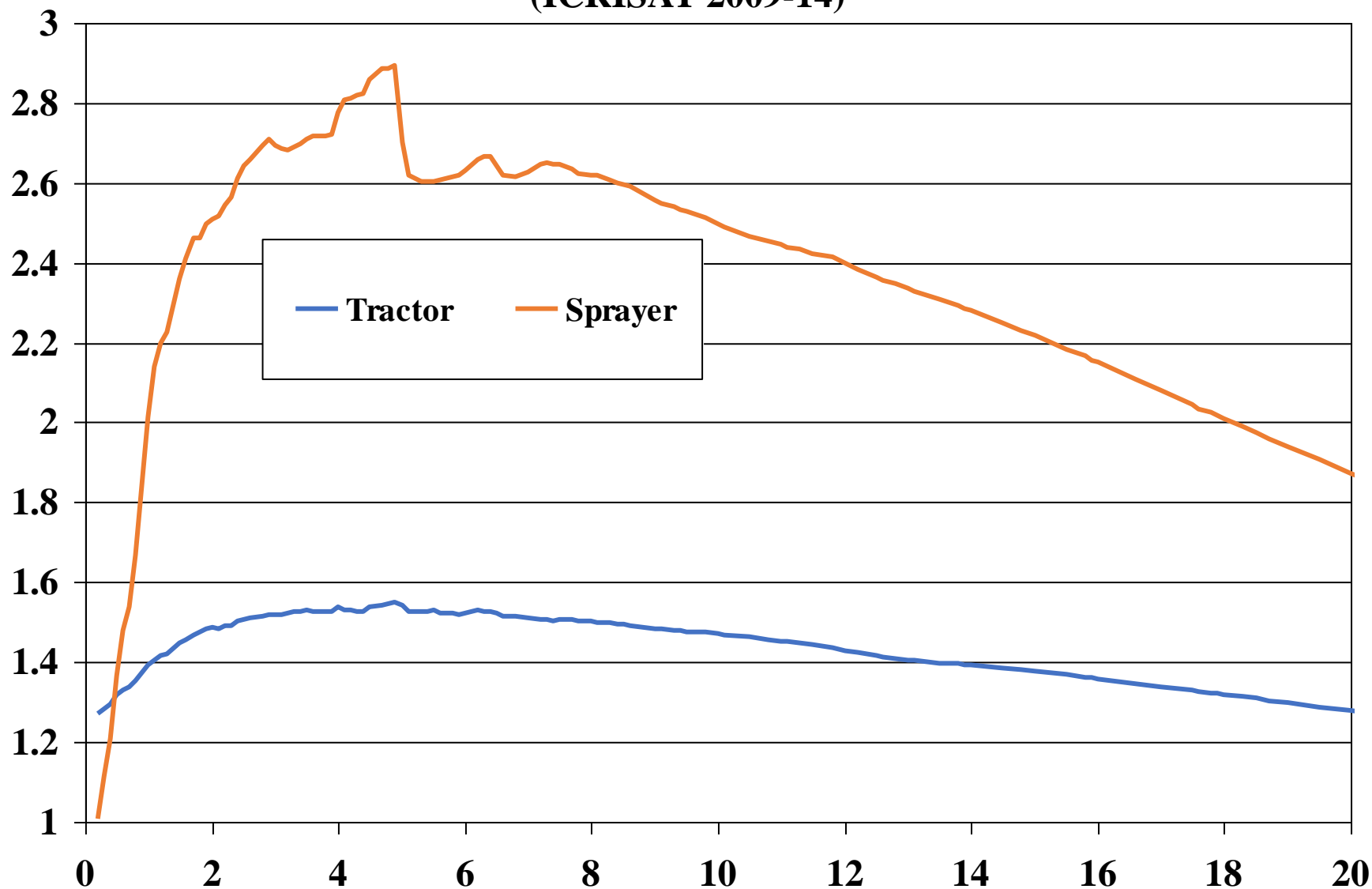
Larger farms are more likely to be using (and owning) mechanized equipment (tractors, threshers, sprayers).

But average hours of use per acre declines with farm size for the larger farms for tractors and sprayers - consistent with the use of higher-capacity equipment.

We will focus on mechanized (power) sprayers for 2 reasons:

- A. We can measure q : the ICRISAT data only provides this key information on capacity q for sprayers.
- B. We can directly measure the costs savings from spraying weedicide - less labor used for weeding (l).

Per-Acre Equipment Hours for Tractors and Sprayers, by Farm Size
(ICRISAT 2009-14)



Sprayer technology is not the sole source of economies of scale due to mechanization, but it is the most important and we can identify scale economies for this input.

Weed management via spraying and hand weeding is an important operation:

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

While tractors are used by almost all farmers, for land preparation, total tractor costs account for less than 2.7% of all costs.

We will be able to quantify how much of the rise in per-acre profits with farm size is due to scale economies in sprayers.

Capacity for a sprayer is typically given in spray rates for a given nozzle size - the amount of material sprayed per unit of time.

Flow rates of one nozzle translate directly into area sprayed, given a target amount of material per area.

The ICRISAT survey data provides the amount (cost) of material used for spraying in a given operation and the hours of spraying.

So we can measure capacity (the flow rate of the sprayer used by the farmer).

We see that sprayer capacity rises with acreage across ICRISAT farmers.

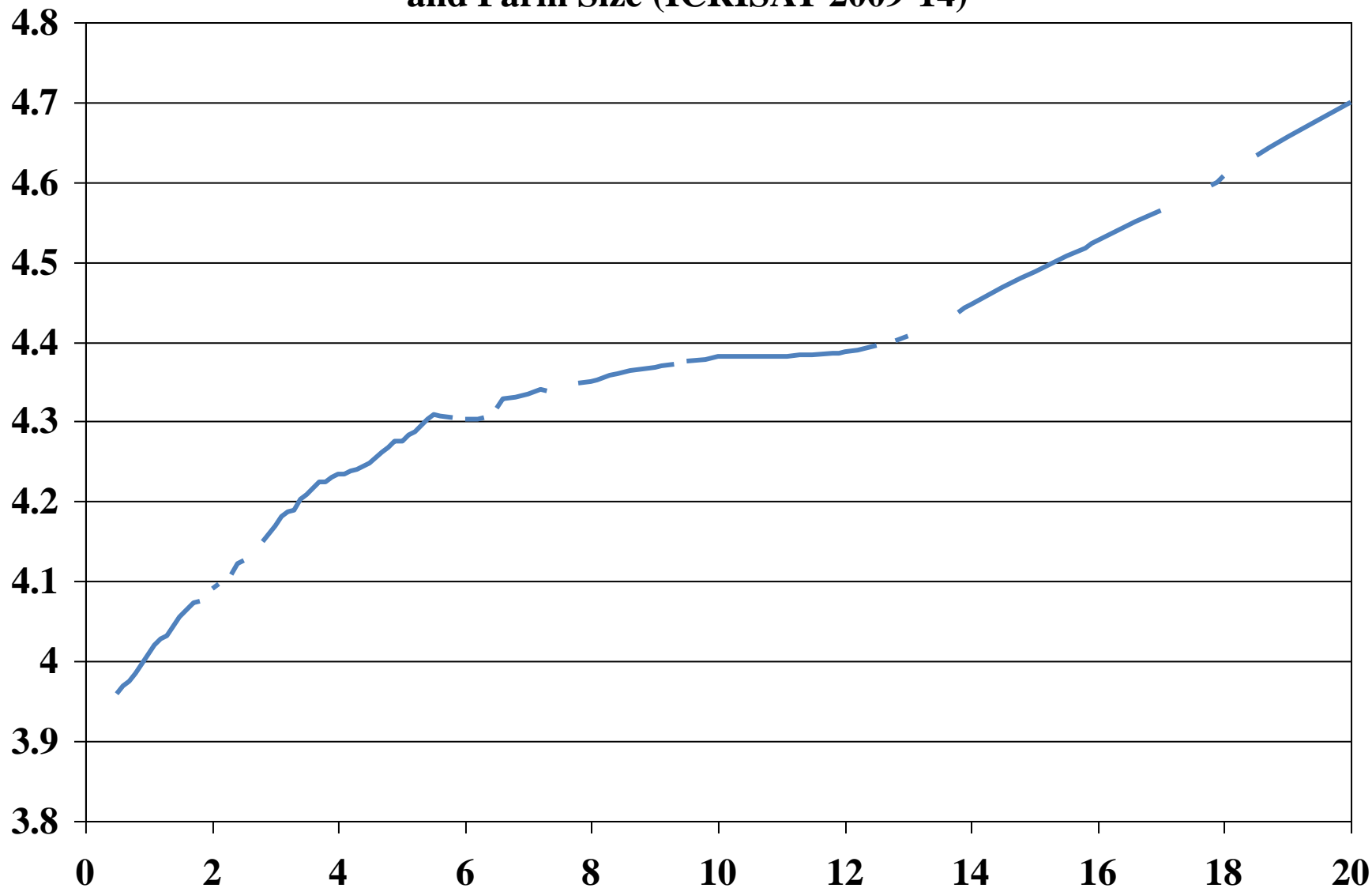
The rise and then fall in per-acre hours for sprayers and the increase in the amount sprayed suggest:

Substitution to higher-capacity sprayers as acreage increases.

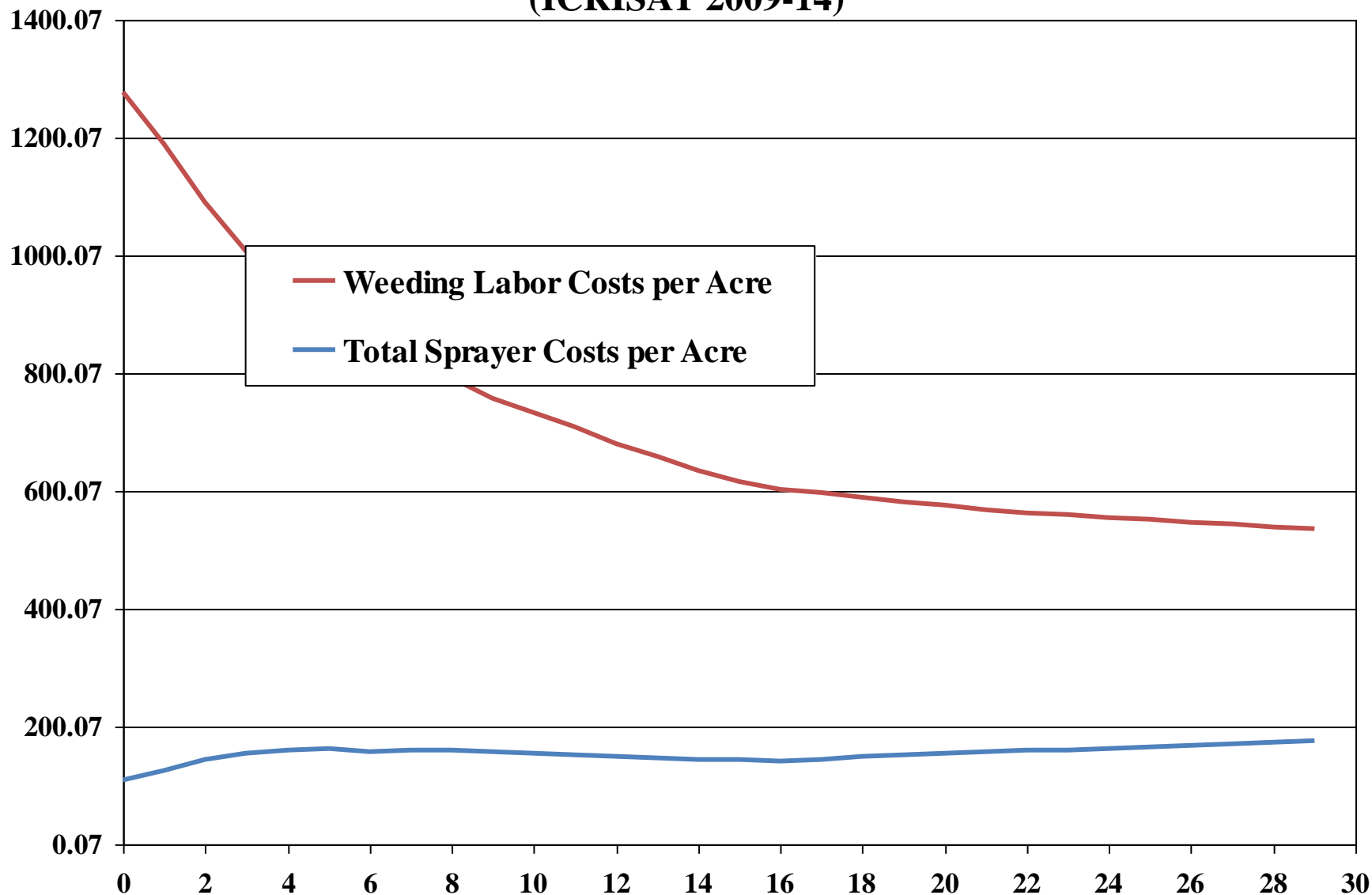
We also see a fall in per-acre weeding labor costs with acreage with little increase in per-acre sprayer labor costs, suggesting:

Substitution of weeding labor by mechanized spraying.

**Relationship Between Log of Sprayer Capacity (Real Value of Material Sprayed)
and Farm Size (ICRISAT 2009-14)**



Weeding Labor Costs and Total Sprayer Costs per Acre, by Farm Size (ICRISAT 2009-14)



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 schedules exhibit equipment economies of scale.

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





Farmers with more acreage are more likely to use a sprayer.

Table 7
Farm Size, Wealth and Mechanization (Ownership): 2014 ICRISAT Round

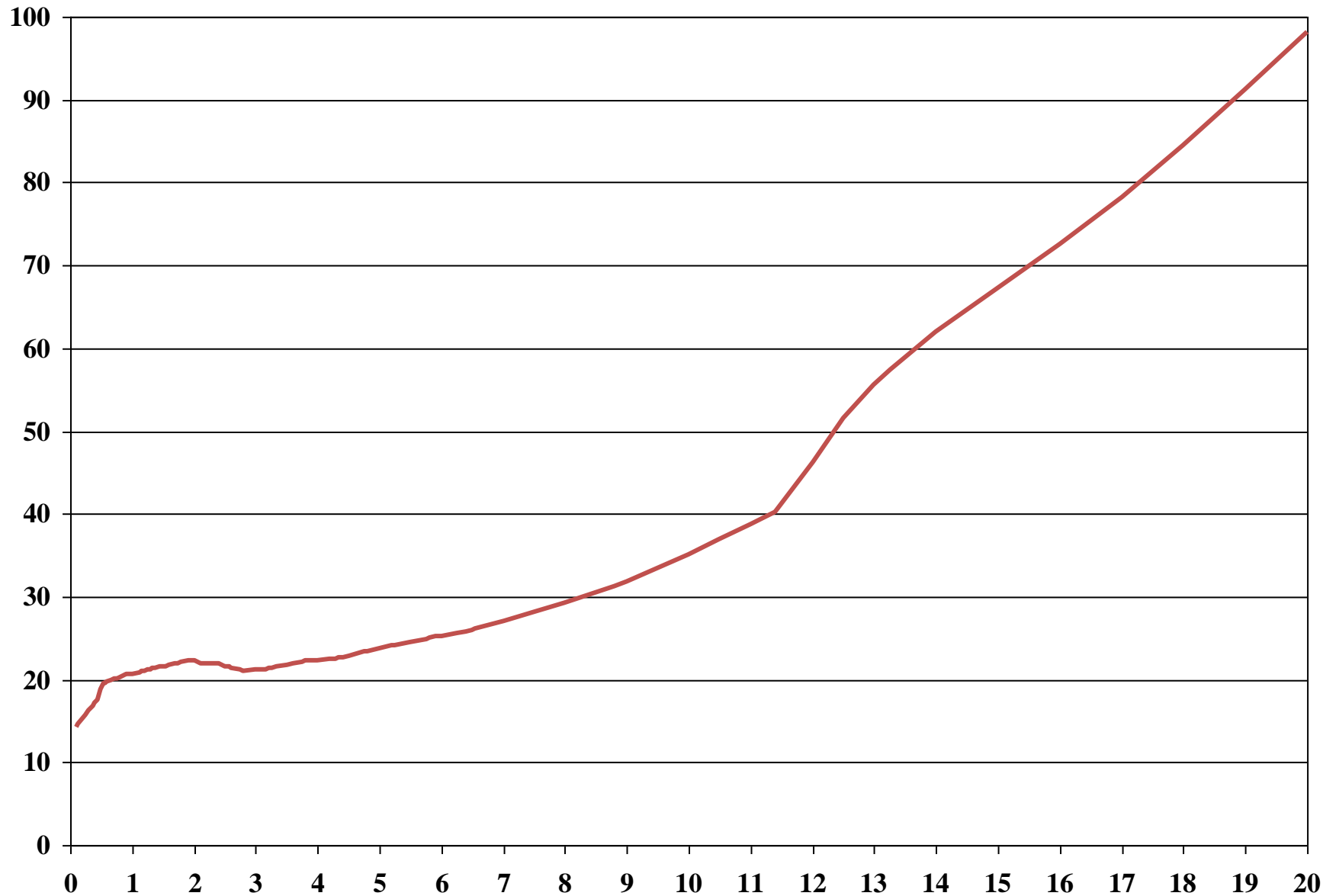
Variable	Owns a Tractor	Owns a <i>Power</i> Sprayer	
Sample	All Farmers	All Farmers	Farmers Who Own Any Sprayer
Total owned land (acres)	.0125 (.00415)	.0107 (.00474)	.0133 (.00494)
Total rental value of land (wealth) x 10 ⁻⁵	.0506 (.0146)	.0512 (.0166)	.0273 (.0144)
Village FE	Y	Y	Y
Percent owning	3.5	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.

Table 8
Cost and Capacities of Indian KrisanKraft Power Sprayers, 2017

Power sprayer	Litres/Hour	Current Price (Rupees)
 <p>KK-708 Knapsack Power Sprayer</p>	180	7830
 <p>KK-PPS-P764 Portable Power Sprayer</p>	420	12260
	1320	25900
	2400	27900

Price per Hour of Sprayer Used, by Plot Size



We also test to see if:

- A. As area increases, per-acre weeding hours declines.
- B. As area increases, per-hour costs of the sprayer increase: suggests the use of more powerful sprayers.
- C. As area increases there is more output (material sprayed) per-acre from spraying.
- D. As area increases, total labor hours per-acre for labor used in spraying per acre declines.

Table 9
Estimates of the Effects of Owned Land Size on Sprayer Use, Weeding Hours per acre,
Sprayer Hours per Acre, Log Sprayer Price per hour, and Sprayer Flow Rate

Variable	Any sprayer use	Weeding hours per acre	Sprayer hours per acre	Sprayer log price per hour	Sprayer flow rate
Owned area	0.00620 (0.000988)	-0.5631 (0.1286)	-0.4063 (0.0853)	0.01335 (0.00669)	0.01360 (0.00667)
All land characteristics	Y	Y	Y	Y	Y
Village/year fixed effects	Y	Y	Y	Y	Y
N	3,374	3,374	1,219	1,219	1,219

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

Estimating Sprayer Scale Economies

We can test directly for scale economies in sprayers:

We estimate:

v , the price schedule parameter for sprayers

the optimal effective capacity function $\varphi(a)$ for sprayers.

We need the prices of sprayers by their capacity - flow rates per unit of time - as in the posted price schedule.

We have the spray rate per hours of sprayers used and the rental price per hour of sprayers in the ICRISAT data.

Capacity and price are determined jointly by the farmer according to two moment conditions from the model.

We re-arrange the panel data and difference across pairs of randomly-selected farmers i and i' within each village/year.

This eliminates the additive year and village/year-specific base prices and wages (p and w).

We then use these two moment conditions from the model:

$$E \left(\frac{(1-\nu) q_{ij}^{\nu} \phi(a_{ij}) - (2-\nu) q_{ij}^{\nu+1}}{(\phi(a_{ij}) - 2 q_{ij})} - \frac{(1-\nu) q_{i'j}^{\nu} \phi(a_{i'j}) - (2-\nu) q_{i'j}^{\nu+1}}{(\phi(a_{i'j}) - 2 q_{i'j})} \middle| a_{ij}, a_{i'j} \right) = 0$$

$$E \left(\ln(x_{ij}) - \nu \ln(q_{ij}) - \ln(x_{i'j}) - \nu \ln(q_{i'j}) = 0 \middle| a_{ij}, a_{i'j} \right) = 0$$

We parameterize the $\varphi(a)$ function as

$$\varphi(a) = b_0 + b_1a + b_2a.$$

We employ GMM using land area and land area squared as instruments to estimate v and the b_k along with standard errors.

We can test if $v < 1$, and compare our estimate to those from actual price schedules.

Given the quadratic form of $\varphi(a)$ we can also identify the maximum land size, if any, at which Indian farmers cannot further exploit equipment (sprayer) scale economies.

Table 10
GMM Estimates of the Effective Capacity Function $\varphi(a)$ and Price Parameter v

Coefficient	Point Estimate	Robust SE
v	0.316	0.124
b_0	5.58	0.0375
b_1	0.933	0.0343
b_2	-0.0190	0.00211
$H_0: v < 1, \chi^2(1) [p]$	30.4 [.0000]	
Maximum land size (acres) = $\varphi(a)' = -b_1/(2*b_2) = 0$	24.5	1.84
N	617	

Instruments: owned land area and land area squared.

Key finding:

Scale economies for sprayers peter out at 24.5 acres.
(95% confidence interval: between 21 and 28 acres)

This is not surprising, and an important result:

There are few farms above 25 acres in India. Thus we would not expect to observe technologies suitable for farms above 25 acres to be marketed there.

But, the acreage at which scale economies peters out is *less* than the scale at which average profits per acre are maximized.

To identify optimal farm scale we need the full model.



RMUS Crop Spraying Drone™ -- DJI AGRAS MG-1S

“The combination of speed and power means that an area of 4,000-6,000 m² can be covered in just 10 minutes, or 40 to 60 times faster than manual spraying operations.”

Table 11
Estimates of Sprayer ν , by Source

Country	India		United States
Source	ICRISAT Survey (2009-2014)	KrisanKraft Price List (2016)	Stiles and Stark (2016)
Estimation procedure	GMM ^a	OLS	OLS
ν	0.316 (0.124)	0.521 (0.0605)	0.146 (0.0789)
$H_0: \nu = 1, [p]$	$\chi^2=30.4$ [0.0000]	F(1,2)= 62.8 [0.0156]	F(1,2)=117.1 [0.0084]
N	1,219	4	4
Village/year fixed effects	Y	N	N

^aFirst-stage includes log of owned area and all land quality characteristics. Standard error clustered at the village/year level.

Calibration of the Full Model

Uses the estimates of the sprayer capacity and pricing functions and fit to other moments of the data to obtain parameter estimates.

Three principal aims:

1. Assess whether the full model replicates the observed U-shape in per-acre profitability and other moments of the data using estimated and plausible parameters.
2. Calculate the optimal size of farms, at equilibrium prices and given the existing technology of machines in India.
3. Counterfactual of changing the land distribution so all farms are at the conditional optimal size: consolidation.

The calibration will also enable the identification of:

1. Both hiring costs w_0 paid by farmers and the fixed cost of entry to the labor market of workers f , which is not observed in the data.
2. The marginal product of labor on autarchic farms, which is also not observed in the data and is a function of all of the model parameters.
3. The typical true marginal cost of labor on larger farms that takes into account hiring costs when multiple workers are hired.

Team hiring? -> lower average fixed costs of labor.

Parameterizations and adjustments to the basic model

To go from a one operation model to a more realistic model to fit to farm data:

- A. Assume that all operations have the same parameterization.
- B. Mean number of operations per farm in the data is 12.
- C. Based on the assumption that a male family worker works full-time when hired labor is used, we obtain from the data that a typical operation takes one day on the smallest farms and peaks at 1.5 days for the largest.

So 21 days of operation in a season.

The production function is assumed to be

$$(15) \quad \psi g(a, e) = \psi a^\alpha \prod_{i=1}^D e_i^{(1-\alpha)/D}$$

where $D (=21)$ is the total number of days worked and e_i denotes nutrients provided on day i , produced according to the e production function:

$$(5) \quad e(l, q, m) = (\omega l^\delta + ((1 - \frac{q}{\phi(a)}) q m)^\delta)^{1/\delta},$$

where q = machine capacity m = machine hours.

We have estimates of v , of w_1 , and the parameters of $\phi(a)$

The data tell us that most agricultural workers work no more than 8 hours, so $l_{mx}=8$ and average family labor endowment = 3 workers.

We estimated the fixed hiring cost for one worker from the data.

But farms may hire multiple workers for the same operation.

While the data indicate the per-worker hiring cost rise with acreage, it is possible hiring multiple workers can be done by team or there are scale economies in hiring workers.

Thus, hiring costs are allowed to vary linearly with acreage.

$$w_0' = w_0 + m_0 a$$

Solve model assuming profit maximization for given land size and family size.

Fit to two moments: Profits per acre and output per worker.

The calibrated structural parameters values are:

$$[\alpha = .381, \psi = 484, \omega = .814, f = 41.7, \\ \delta = .928, p_m = 25.3, w_0 = 159, m_0 = .761]$$

1. Implied elasticity of substitution from δ is high = 13.9.
2. $w_0' = \text{Rs.}159$ for the mean-sized farm (3 acres), compared with 177 from the wage data, and increases with acreage.
3. $f = 41.7 < 159$: village-based workers benefit on average.

Presumably the last worker hired is from outside.

4. Marginal product of an inframarginal *hour* on autarchic farms (three family workers):

Maximum (at estimated $a^{**}=9$ acres) = Rs.53.8.

Mean = Rs. 43.9

Marginal product of an inframarginal hour on farms selling or buying labor = Rs.21 (less than 1/2)

Thus, the presence of autarchic farms means labor is underutilized and mis-allocated across farms.

But, larger farms hire multiple workers: the largest farm, the per-hour marginal product, taking into account the hiring costs, for hiring *one worker* = Rs.43.1.

Model Fit

Targeted fit: profit per acre and output per worker by area.

Non-targeted fit:

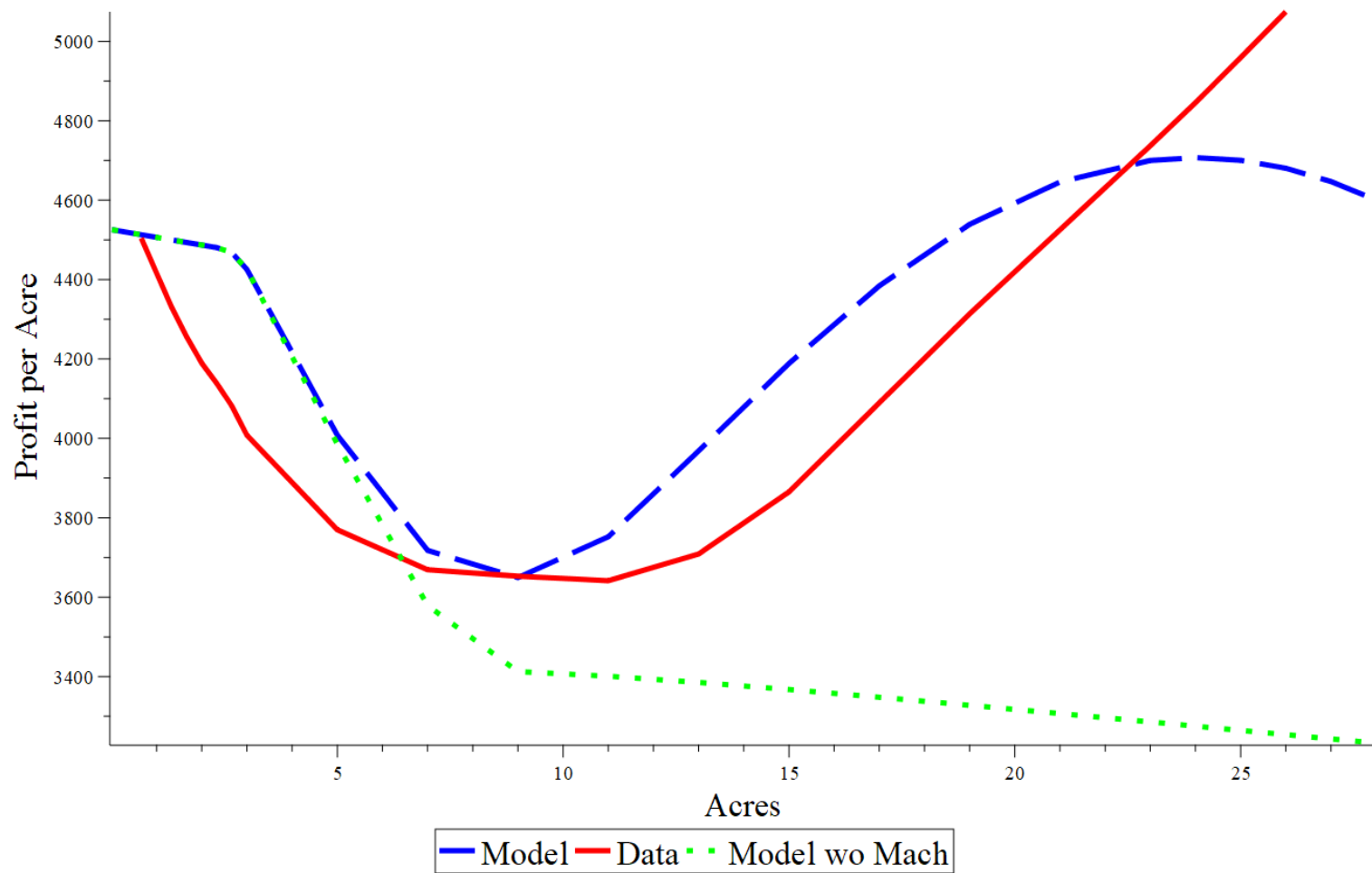
A. Predicted number of worker hours by area.

B. Predicted fraction of farms in autarchy = 33.8% (34%).

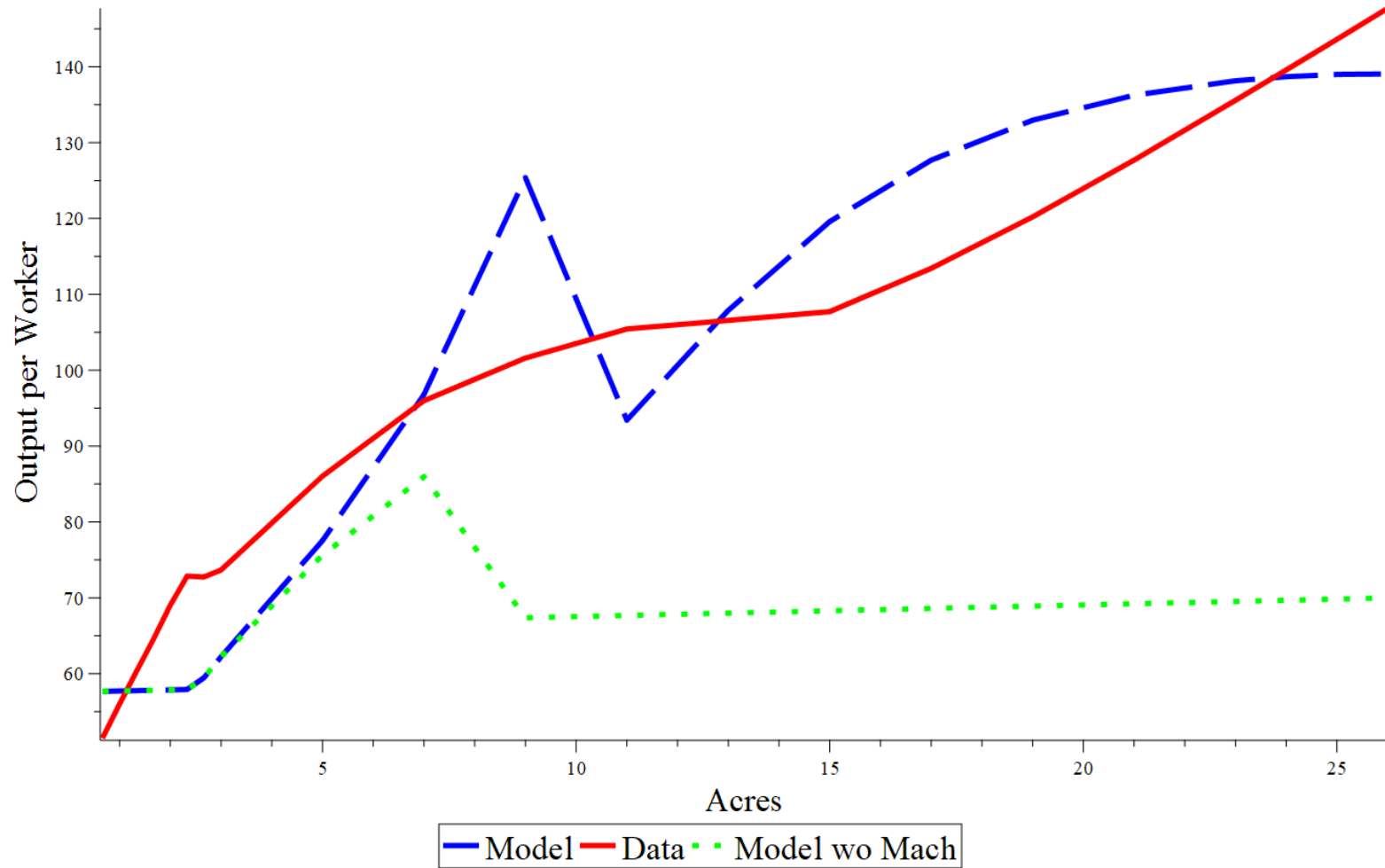
Counter-factual: agriculture without machinery

Main gains from expanding acreage beyond a^{**} come from machine capacity scale economies.

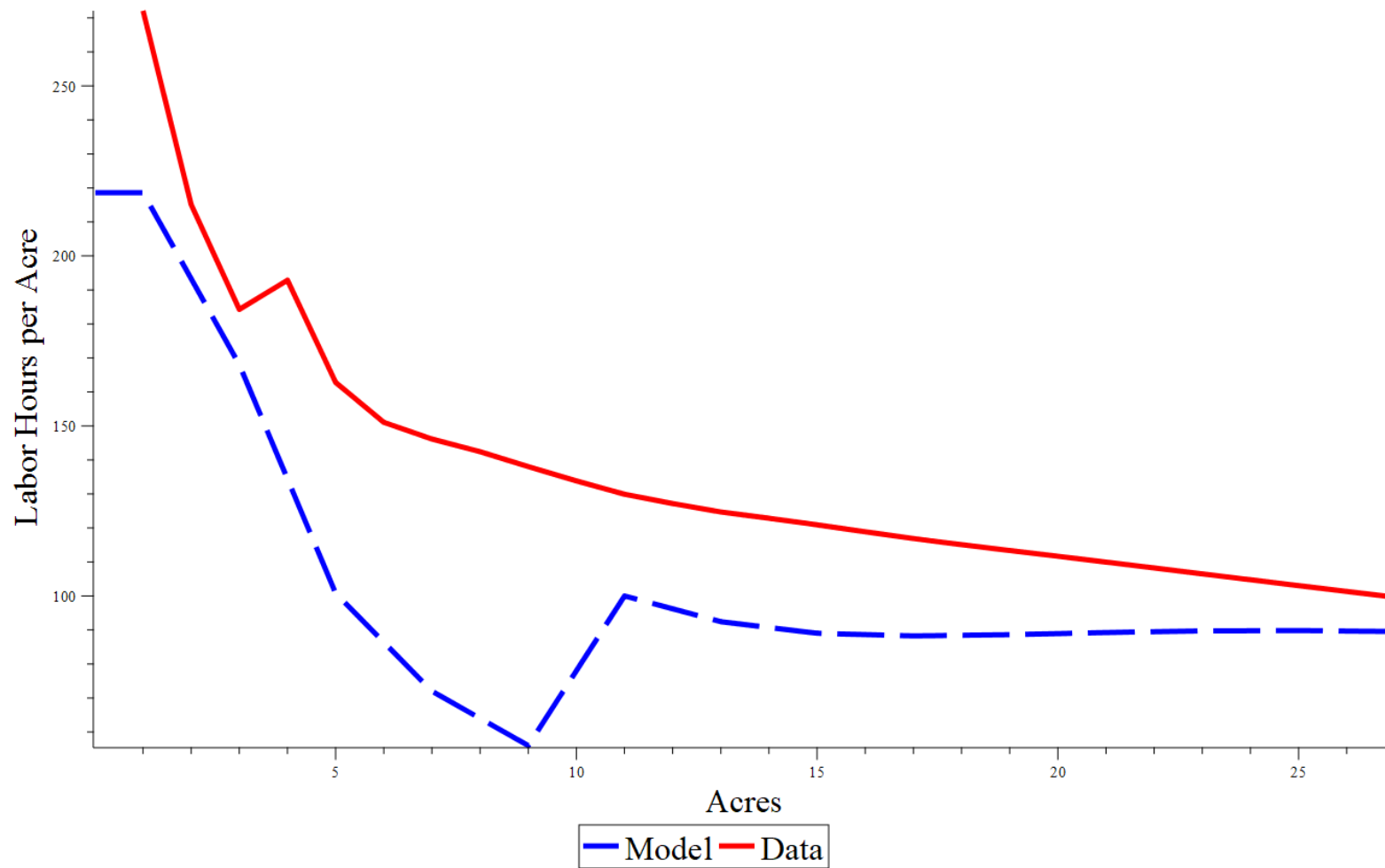
Model Fit: Profit per Acre and Land Size



Model Fit: Output per Worker and Land Size



Model Fit: Labor Hours per Acre and Land Size



Hypothetical Consolidation Counterfactual: Moving to a world with optimally-sized farms

Use calibrated model parameters to carry out a hypothetical counterfactual that changes the existing distribution of farms to:

All farms optimally-sized based on the current available technology in India.

Gains from:

- A. Maximal exploitation of machine scale economies.
- B. Eliminates autarchic farms and differences in hiring costs across farms - eliminates labor mis-allocation across farms and the underutilization.

We need to expand the model to an equilibrium model:

Expanding land size will reduce labor use per acre, as the estimates show.

This may change the equilibrium wage.

Arthur Lewis-type “surplus labor” model - shift of workers out of agriculture does not reduce the wage.

Best available estimates of the urban wage elasticity of labor demand in India (Lichter *et al.*, 2015; Goldar, 2009) = -0.4.

The equilibrium is a fixed point: optimum farm size depends on the cost of labor (wage) and affects the demand for labor.

Adjustments for application to the whole Indian economy:

A. Translate hours of labor use to labor force size:

ICRISAT data: 1023 agricultural workers (farmers plus wage workers in agriculture) supplied 188,101 hours of work in total.

Assume ratio stays constant, as number of operations are independent of scale.

B. Number of farms in India from the 2011 Indian Census.

C. Size of urban labor force in India from the 2011 Indian Census.

1948 United Provinces Zamindari Abolition Committee Report:

“Consolidation has been regarded as the very first step towards improvement of agriculture by agrarian economists all the world over. ... perhaps, a combination of compulsory and co-operative methods coupled with the taking over by the State of the cost of consolidation, or, a very large part of it, would accelerate the process of consolidation at the desired pace. A national or governmental drive from the top ...”

“On the basis of 10-acre-holding 81 lakhs, i.e., over 66 per cent [of the total number of cultivators], would be displaced.”

“In industrialisation lies the solution of the problem of agricultural over-population in a large degree.”

Table C
Calibrated Equilibrium Effects of Making All Farms of Optimal Size

Scenario	Baseline	Post-Reform	Post-Reform
Urban wage elasticity	-	0	-0.4
Average farm size (acres)	3.13	24.0	24.1
Number of farms (millions)	95.2	12.4	12.4
Profits per acre (Rs)	4276	4705	4845
Total agricultural output (trillion Rs)	2.71	3.71	3.85
Profit per worker (Rs)	6302	9634	9225
Output per worker (thousand Rs)	14.5	25.4	24.4
Hourly wage (Rs)	21	21	19.2
Size of agricultural labor force (million)	187	146	158
Work hours per farm	361	2157	2340
Machine hours per farm	58.5	163	162
Fraction of farms using machines	.213	1	1
Machine capacity index (mode)	4.49	7.74	7.72

Counterfactual Results (-0.4 elasticity)

1. Change from a farm size mean of 3.1 acres to 24.1 acres.
2. Reduction in the number of farms of 87%.
3. Reduction in the size of the labor force of 16%.
4. Total output *rises* by 42%
5. Output per worker *rises* by over 68%.

There are 82.8 million surplus farms.

There are 29 million surplus agricultural workers.

Note: there is a wage decline of 8.6% (0 if Lewis equilibrium, with slightly higher output per worker).

What are the sources of the gains:

- A. Reduction in the marginal cost of inputs from the use of higher capacity machines and savings on transaction costs.

Mode machine capacity rise by 72%.

All farms now use machines (0.71 machine hours per acre at 7 acres \rightarrow 3.8 at 24 acres.

- B. Reduction in the workforce, via labor/machine substitutability.

Given the high elasticity of substitution between labor and machines, why not a much larger reduction in the workforce (“only” 16%)?

Transaction costs of labor!

Because of these costs and small scale, autarchic farming is common - 52% of total land cultivated.

On these farms, labor is under-utilized, restricted to the family.

No autarchic farms in the new regime.

Labor is more fully utilized.

How restricted is labor use on autarchic farms?

One acre farm (with off-farm labor): 9.7 hours/acre per day.

9-acre autarchic farm (at a^{**}): 2.7 hours/acre per day.

24-acre farm: 4.75 hours/acre per day.

Labor utilization is substantially less than it would be without labor market transaction costs.

Conclusion:

1. Indian agriculture is less productive and its labor force substantially poorer because of the small scale of agriculture and the existence of labor transaction costs.
2. Larger scale farming would permit exploitation of available machine scale economies, a reduction in unit labor costs, and substantially eliminates the under-utilization of labor associated with autarchic production.
3. The “optimal” farm size is based on the existing technology available in India. Because of the scale economies of machines, the availability of technology is itself an equilibrium that depends on the scale of farming.

Note: While there is more output to divide among the (smaller) rural population, the equilibrium is characterized by lower wage rates for the landless, whose number would increase absent surplus labor in the Lewis sense,

This counterfactual expansion of farm scale is one way to gauge the cost of smallholder agriculture.

Actually moving to a new equilibrium with fewer farms would have challenges:

Absorbing an increase in the urban workforce so there is no reduction in the equilibrium wage is one.

Transitioning farmers to landless workers from the massive reduction in farms of 87% is another.

But, if larger scale is more profitable for farmers, why do farms remain small?

Why no leasing to increase scale (<10% of farmers rent or sharecrop)

And how is it that less efficient autarchic farms co-exist with more profitable larger and smaller farms?

The answer is in the U-shaped per-acre profit curve:

There is a massive chasm separating small and more-profitable big farms.

Most farms are operating on the downward slope of the curve.

A marginal expansion of acreage from purchasing or leasing a similar-sized contiguous farm would *reduce* profitability per-acre for such farmers:

Thus, the selling price, reflecting the discounted lifetime earnings stream from the land to the seller, would exceed the gains to the buyer.

Only the consolidation of multiple contiguous plots to move over the chasm would be profitable - necessitating simultaneous transactions among many farmers.

If the mode farm were 3 acres, it would take 6 or 7 deals to expand production to the “optimal” scale.



