Are There Too Many Farms in the World? Labor Market Transaction Costs, Machine Capacities and Optimal Farm Size by Foster and Rosenzweig (2017)

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BU

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Motivation

Three stylized facts:

1. Farming in low-income countries - small-scale
   Farming in high-income countries - large-scale Figure 1

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2. The productivity of developed-country agriculture is substantially higher than it is in low-income countries

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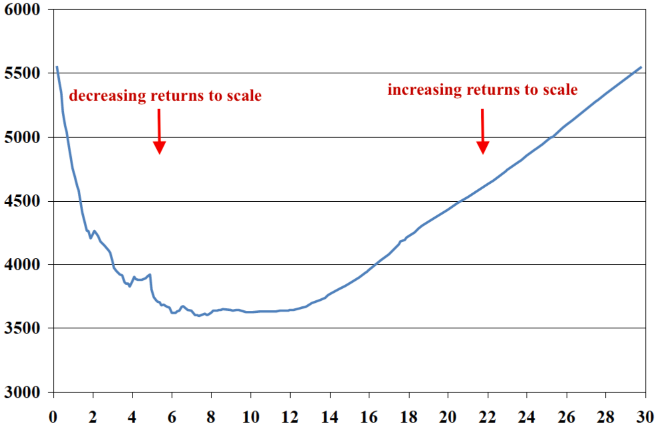
Three stylized facts:

1. Farming in low-income countries - small-scale
   Farming in high-income countries - large-scale Figure 1
2. The productivity of developed-country agriculture is substantially higher than it is in low-income countries
3. A **U-shaped pattern** b/w productivity and farm/plot size

Motivation (Cont'd)

Figure 6. Relationship Between Real Average Profits per Acre and Farm Size (Acres) (ICRISAT VLS 2009-14)



Main Question

- Given the global pattern of farm productivity, why is there a **U-shape** relation b/w farm productivity and scale?
    - Why are the smallest farms more productive than less small farms?
    - Why in the developed world, the larger-scale farms are more productive and that productivity increases with the farm scale?

This Paper

- Explains the U-shaped relationship b/w farm productivity and farm scale from two factors:
  1. Transaction costs in the labor market
     - A large % of low-hour workers ($\leq$ 8 hours/day)
     - $\uparrow$ hourly wages to lower-hour workers $\Rightarrow$ fixed transaction costs for hiring workers (transportation costs)
     - Can explain the U-shape, but cannot alone account for the higher productivity of larger farms compared to the smallest farms
  2. Economies of scale in machine capacity
     - The cost per horsepower (-) related to the total horsepower

Overview of the Presentation

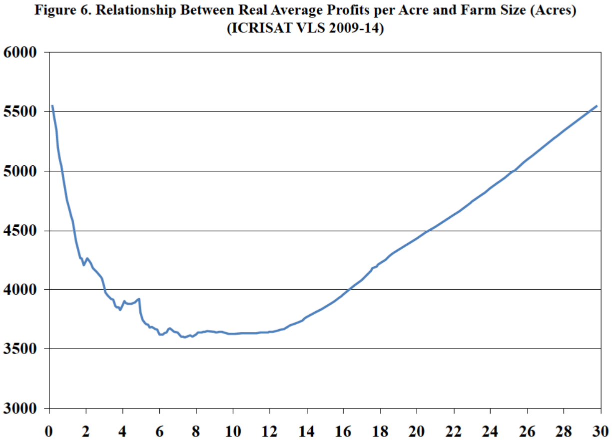
Literature

- An inverse relation b/w farm prod. and size in low-income countries
  - Asia & Latin America (Hazell, 2011; Vollrath, 2007; Kagin *et al*., 2015
  - Africa (Larson *et al*., 2013; Carletto *et al*., 2013)
- Explanations for the inverse relationship
  - Superior incentives, lower supervision costs, and lower unit-labor costs
    - Yotopoulos and Lau, 1973; Carter and Wiebe, 1990; Binswanger-Mkhizee, *et al*., 2009; Hazel *et al*., 2010
    - Cannot explain why large-scale farms are more productive
- **Two prior studies that finds evidence of a U-shape**
  - Kimhi (2006):
    - Dis-economies of scale in small maize farms in Zambia, but economies of scale above a threshold
  - Muyanga and Jayne (2016)
    - medium-sized and small farmers in Kenya in the same villages
  - Neither provides evidence on the mechanisms behind the U-shape

Data

- Six latest rounds of the India ICRISAT VLS panel survey
  - Covers the agricultural years 2009-2014
  - Contains
    - a census of all households in 18 villages in five states
    - a panel survey of the households in those villages (819 farmers)
  - Contains in equal numbers landless households, small-farm households, medium-farm households, and large-farm households
    - Could examine both small and larger farms in a common environment
  - Also provides information on input quantities and prices; market input prices for workers, machinery, and animal traction; measurement of the power and capacities of machines

Establishing the Fact: the U-shape



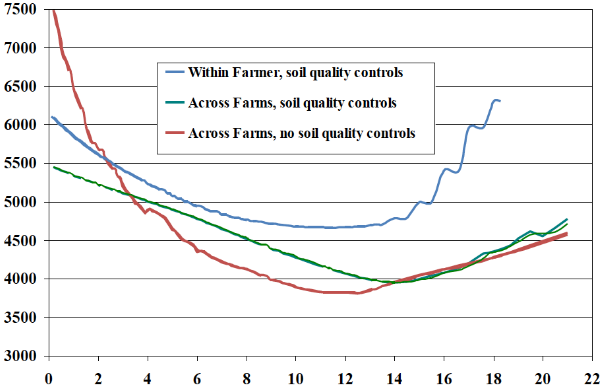
[0] Profits are from the main growing season and are measured in 1999 rupees

Establishing the Fact: the U-shape (Cont'd)

- Ruling out the possibility of a spurious correlation
  - Measurement error?
    - Use the total farm size from the Census elicitation to IV for the total farm size from the survey $\Rightarrow$ not the main cause
  - Land quality, credit constraints & farmer ability

Establishing the Fact: the U-shape (Cont'd)

Figure 8. Real Profits per Acre by Owned Area: Roles of Plot Quality and Farmer Characteristics (ICRISAT VLS 2009-14)



- All graphs (with soil characteristics, farmer FE) exhibit a U-shape ⇒ neither farmer wealth/ability nor plot/soil quality could explain the U-shape

Labor-only Model

- One-stage agricultural production
- The production of output requires land and nutrients; CRS production function $g(a, e)$
- The production process for nutrients requires only labor $e = l_f + l_h$
- Households choose b/w family labor (l_f), hiring outside labor (l_h) for their own-farm production
  - Hired labor: has a fixed cost; $w(l_h) = \mathbb{1}(l_h > 0)w_0 + w_1 l_h$
  - Family labor: no fixed cost; $w_1 l_f$
- With the time endowment, households could either work on farm or enter the labor market; $l = l_o + l_f$
- There is a fixed cost f if they enter the labor market
- HH income comes from: working on farm & entering the labor market
- Household cost comes from: hired labor cost & family labor cost

Labor-only model

Farmer maximizes:

$$\pi = g(a, l_h, l_f) - \underbrace{w(l_h)}_{\text{if hire a worker}} - \underbrace{w_1 l_f}_{\text{family labor cost}} + \underbrace{\mathbb{1}(l_o > 0)(w_0 - f) + w_1 l_o}_{\text{if work off-farm}}$$

subject to the constraint: $l_o + l_f = l$

- Three regimes:

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  - I. $a < a^*$: family members work both on and off farm

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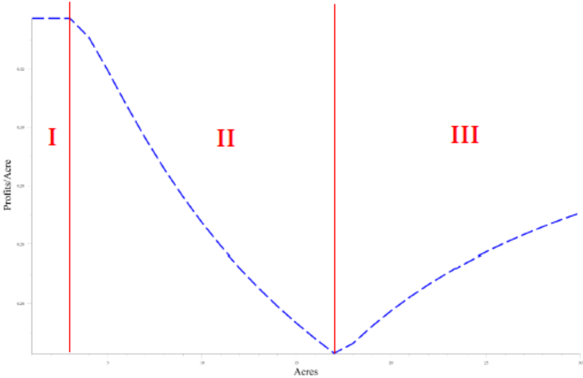
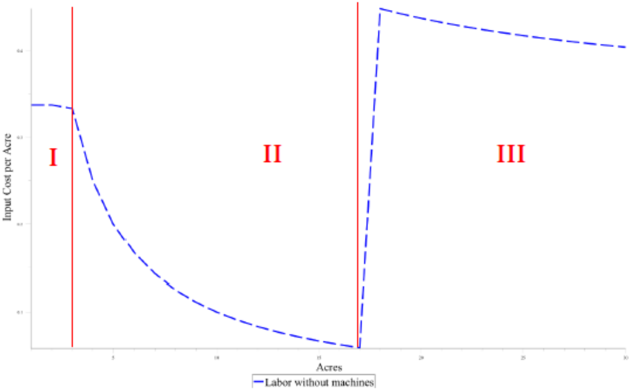
- Two thresholds: a^*, a^{**}
  - a^*: Households are indifferent b/w entering and not entering the labor market
  - a^{**}: Households are indifferent b/w hiring and not hiring workers

Simulation: profits per acre by farm-scale



- On the smallest farms, farm size has no effect on farm profits
- At 2.5 acres, farms become autarchic, and profitability per acre ↓ in land size due to the ↑ marginal cost of l_f
- At 11.8 acres, the per-acre farm profits increase in farm size

Simulation: input costs per acre by farm-scale



- I: On the smallest farms, farm size has no effect on input costs
- II: Per-acre input costs fall due to constant family labor and ↑ farm size
- III: Input costs rise discontinuously due to the fixed labor costs and decrease as acreage rises

Comments and Critiques 1:

What is the constraint of l_h?

- If $0 < l_h < l$
  - land per labor ↑ with size ⇒ profits per acre would eventually decrease in Regime 3 X
- If $0 < l_h < \infty$ (could hire infinite number workers)
  - should see repeated jumps for input costs per acre each time a new worker is hired X

Identifying Scale Dis-Economies due to Labor Market Transaction Costs

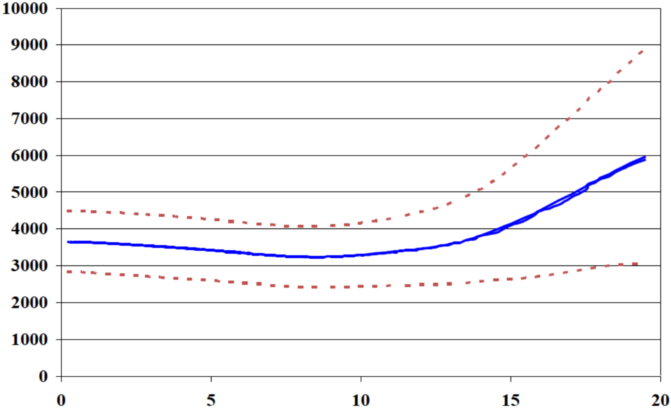
- Testing for varying β_1 coefficients in the profit function by land size using LWFCM (Locally Weighted Functional Coefficient Model)

$$y_{ijt} = \beta_0(a_{ij}) + \beta_1(a_{ij})a_{ij} + \sum \beta_n(a_{ij})X_{ijt} + \delta_{jt}(a_{a_{ij}}) + \eta_{ijt}(a_{ij})$$

  - y_{ijt} - total profits over the *kharif* season for a farmer i in village j in year t
  - X_{ijn} - soil characteristics
  - δ_{jtk}- village/time fixed effects
  - η_{ijt} - time-varying land specific iid errors
- A Priori:
  - a_{ij} very small $\rightarrow \beta_1(a_{ij})$ does not vary w.r.t. a_{ij}
  - a_{ij} small $\rightarrow \beta_1(a_{ij}) \downarrow$ in a_{ij}
  - a_{ij} large $\rightarrow \beta_1(a_{ij}) \uparrow$ in a_{ij}

Identifying Scale Dis-Economies due to Labor Market Transaction Costs (Cont'd)

Figure 16. LWFCM Estimates of the Effects of Land Size on Profits with 95% CI, Net of Soil Quality and Time/Village Fixed Effects, by Farm Size (ICRISAT VLS, 2009-14)



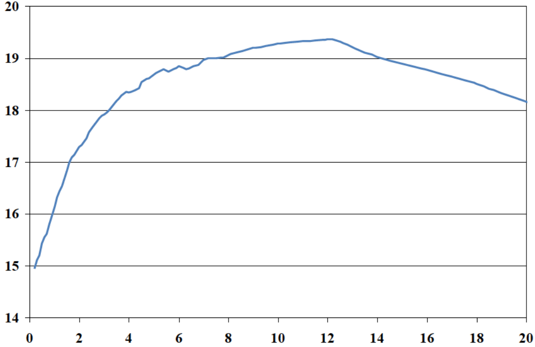
Comments and Critiques 2:

- $\beta_1(a_{ij})$ captures the marginal profits to size, which seems to be DRTS at small farms, and IRTS at large farms
  - But interested in the average profits per acre instead of the marginal profits of size $\Rightarrow$ not a perfect proxy
- Use the level of profits instead of the logarithms in the regression
  - Taking logs of profits could more clearly show the economies-of-scale patterns (e.g., IRTS: $\beta_1 > 1$; DRTS: $\beta_1 < 1$; CRTS: $\beta_1 =1$)

Direct Mechanism Testing

- Moving from the smallest farms to the largest, the avg. hourly wage[1] firstly rises and then falls at some threshold

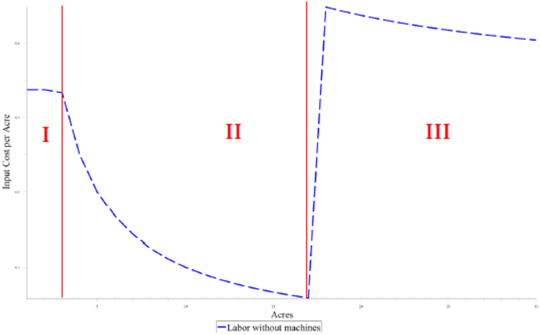
Figure 18. Average Hourly Wage Paid for Male Labor, by Farm Size (ICRISAT VLS 2009-14)



[1] family labor is priced at the marginal or eight-hour wage, while hired labor is priced at the wage actually paid

Comments and Critiques 3:

- What the model predicts: labor costs do not vary with size at small land sizes (stage I), decrease with land sizes at small-to-medium farms (stage II), and increase with land sizes at large farms (stage III)
  - The direct test here only shows the pattern in stage III, but do not show the first two stages



Rainfalls: The marginal land size effect on unit labor costs

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)	.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 and plot 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

- ↑ rainfalls are associated w/ ↑ productivity
- ↑ rainfalls are associated w/ ↑ input hours and lower average input costs

Rainfalls, input usage, and average input costs by plot size

Figure 19. 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 VLS 2009-14)

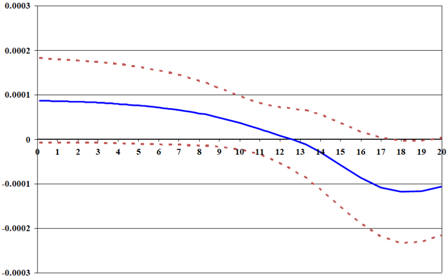
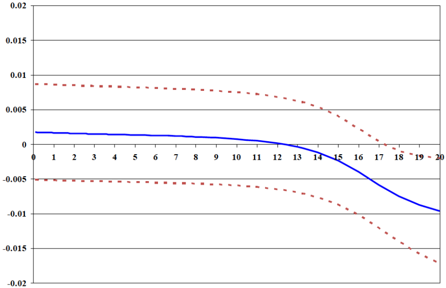


Figure 20. LWFCM Plot Fixed-Effect Estimates:
the Effect of Rainfall on the Average Male Wage, with 95% CI, by Plot Size (ICRISAT 2009-14)



- At small plot sizes
  - ↑ rainfalls are associated w/ a ↑ usage of low-hour labor & a ↑ average hourly labor costs
- At larger plot sizes
  - ↑ rainfalls are associated w/ ↓ usage of low-hour labor & a ↓ average hourly labor costs

Model w/ heterogeneous machine

Limitation of a labor-only model:

- Smallest farms have the highest per-acre profits, contradicting the empirical fact that large farms are most productive

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- Include machine capacity scale economies in farm production

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Solution:

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To have scale economies in farm production:

- Larger farms use higher machine capacity
- Smaller farms use lower machine capacity

Model w/ heterogeneous machine

Additional assumptions:

- add another input, machine: q (machine capacity), m (machine time)
- allow machine time and labor time to be substitutes, the nutrient fn. has a CES form:

$$e(l, q, m) = [\omega(\xi l)^\delta + (1-\omega)(\underbrace{(1 - \frac{q}{\Phi(a)})qm}_{\text{effective machine capacity}})^\delta]^{1/\delta}$$

- $\Phi'(a) > 0$: inefficient to use large capacity on small farms
- total cost of using a machine per unit of time:

$$\underbrace{p_q q^\nu}_{\text{rental cost}} + \underbrace{w\theta}_{\text{labor operating machine}}$$

$0 < \nu < 1$, economies of scale in machinery capacity

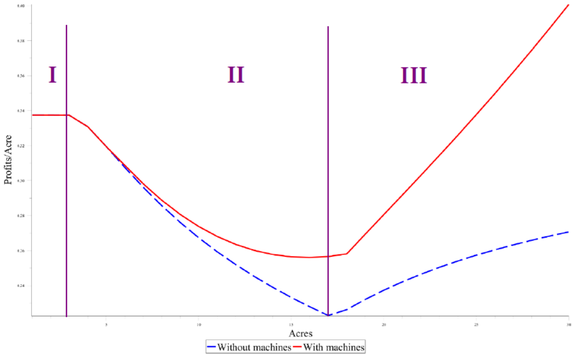
Model w/ heterogeneous machine

So the farmer now maximizes the following profit function over m, q, l_h, l_f given farm size a:

$$\pi(a, l_h, l_f, q, m) = g(a, e(l_h + l_f, q, m)) - w(l_h) - w_1 l_f - (w\theta + p_q q^{\nu})m + \mathbb{1}(l_o > 0)(w_0 - f) + w_1 l_o$$

subject to the constraint: $l_o + l_f = l$

Simulation: profits per acre by farm-scale

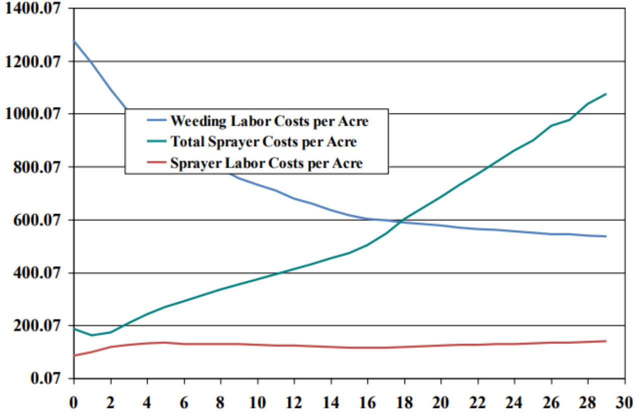


- I: no machine ⇒ profits per acre does not vary w/ size
- II: substitute family labor w/ machine ⇒ profits decrease with size but are higher than the labor-only case
- III: use higher-capacity machine ⇒ profits per acre increase with size and are higher than smallest farms

Case of sprayer

- Data provides info on
  - hours of sprayer usage and the flow rate of a spray
    $\rightarrow$ know machine time and capacity
  - labor weeding hours
    $\rightarrow$ can measure labor savings from spraying
- the most commonly used technology
- substantial differences in sprayer capacities
  - power sprayer: higher-capacity
- capacity $\uparrow$, per unit of capacity sprayer price $\downarrow$

Empirical evidence



- Weeding labor cost per acre $\downarrow$ w/ size: substitute machine for labor
- Total sprayer cost per acre $\uparrow$: use more expensive, higher-capacity machine as farm size goes up

Reduced-form evidence: machine use

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

Variable	Owns a Tractor	Owns a Power 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.

- Farmers with more land area are more likely to own a machine
- Farmer are more likely to own a power sprayer if they own any sprayer

Reduced-form evidence: time spent

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

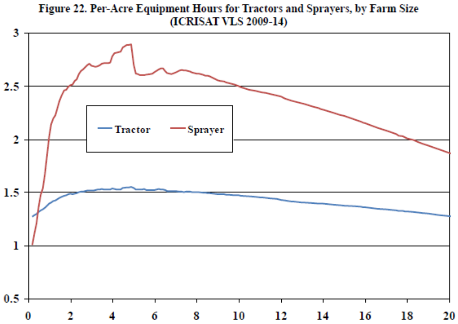
Variable	Any sprayer use	Weeding hours per acre	Sprayer hours per acre	Sprayer log price per hour	Sprayer flow rate
Estimation procedure	OLS	OLS	OLS	OLS	OLS
Owned area	0.006197 (0.0009879)	-0.5631 (0.1286)	-0.4063 (0.0853)	0.01335 (0.00669)	0.01360 (0.00667)
All land characteristics	Y	Y	Y	Y	Y
Village/year 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.

- Large farms are more likely to use more machine
- Larger farms are more likely to reduce labor
- Larger farms are more likely to use pricier and higher capacity sprayers

Comments and Critiques 4:

- A hump-shaped curve for per-acre machine hours by farm size



  - OLS with only one variable *a* cannot capture the curvature
  - better to add a quadratic term,
    or alternatively run linear regressions on a subset of observations

Direct Testing: structural estimation

To test directly for scale economies in spraying and the limits: estimate the machine price parameter ν (recall rental cost $p_q q^{\nu}$) and the effective capacity fn. $\Phi(a)$

- Method: GMM
- Moment conditions: same wage and price across a pair of randomly selected households in each village
- Parameterize $\Phi(a) = b_0 + b_1 a + b_2 a^2$
- IV: a, a^2

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Model implies: $\frac{dq}{da} > 0$ if $\Phi'(a) > 0$

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$\Rightarrow$ if $b_1 > 0$ and $b_2 < 0$, $\Phi(a)$ has a maximum at a^*: $\Phi(a) \uparrow$ first, then $\downarrow$

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$\Rightarrow$ $a \uparrow$, $q \uparrow$ until $\Phi(a)$ is maximized ($a = a^*$)

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$\Rightarrow$ an equilibrium trap - no single farmer would have an incentive to expand land size beyond a^*

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$\Rightarrow$ an equilibrium trap - no single farmer would have an incentive to expand land size beyond a^*

$\Rightarrow$ but if land consolidation $\uparrow$ num. of farms above a^*, high demand from large farms can support a market for higher-capacity machines

Direct Testing: structural estimation

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

Coefficient		Point Estimate	Robust SE
υ	Economies of scale in machine capacity →	0.316	0.124
b_0		5.58	0.0375
b_1	Existence of equilibrium trap →	0.933	0.0343
b_2		-0.0190	0.00211
H_0: $\upsilon < 1$, $\chi^2(1)$ [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.

- Most farms are below the max (24.5) → too many small farms
- There are other barriers to land consolidation
- Yes, there is an excess number of farms

Comments and Critiques 5:

- $\Phi(a)$ quadratic form $\rightarrow$ Too many (small) farms
- No explanation for the functional choice
  - Are the results robust?
  - better to try different specifications of $\Phi(a)$

Direct Testing: comparative statics

Table 12
Elasticities for Changes in Area, υ and Wage Rates on Sprayer Capacity (q), Sprayer Hours (m) and Weeding Labor Hours (l) for a Farm of Median Size (3 acres), from the Calibration and GMM Estimates

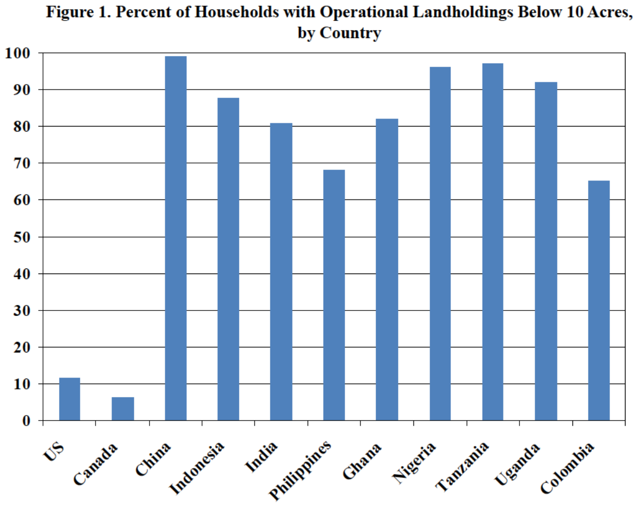
Coefficient	Point Estimate	Robust SE
$dq/d\upsilon$	-0.0498	0.0728
$dm/d\upsilon$	-0.233	0.113
$dl/d\upsilon$	0.0299	0.130
dq/da	0.297	0.0124
dq/dw	0.0292	0.0399
dm/dw	-0.756	0.977
dl/dw	-1.365	0.112

- Cost advantage ↑ (ν ↓): ↑ capacity, ↑ machine time, ↓ labor time
- Wage w ↑: ↑ capacity, ↓ machine time (labor operating), ↓ labor time

Conclusions

- Revisit the U-shaped pattern b/w operation scale and farm productivity in agriculture
- Labor-market transaction costs can explain slightly larger farms are least efficient
- Economies of scale in machine capacity can explain the rising upper tail of the U of high-income countries
- There are too many (small-scale) farms, insufficient to exploit locally-available equipment capacity scale-economies.

Percentage of Small-sized Landholders by Country



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