Achieving Scale Collectively

Vittorio Bassi
USC

Raffaela Muoio
BRAC Uganda

Tommaso Porzio
Columbia GSB and CEPR

Ritwika Sen
Northwestern Kellogg

Esau Tugume
BRAC Uganda

NBER/BREAD Fall Meeting, November 22-23, 2019

Technology Adoption and Indivisibilities

- Why technology does not flow to poor countries?

  - technology often embedded in **indivisible** capital goods (e.g. machines)
  - do indivisibilities hinder technology adoption and productivity?

  $\Rightarrow$ **small firm scale** $\rightarrow$ indivisibility binds for the individual firm

- *This paper*: firms overcome the indivisibility **collectively**

  - document existence of inter-firm **rental market** for indivisible capital goods
  - quantify gains from rental market and study role of policy interventions

- Key messages of our study:

  1. role of clusters: firm-to-firm interactions widen the **firm boundary**
  2. policy effectiveness: leverage **market interactions** between firms

Technology Adoption and Indivisibilities

- Why technology does not flow to poor countries?

  - technology often embedded in **indivisible** capital goods (e.g. machines)
  - do indivisibilities hinder technology adoption and productivity?

  $\Rightarrow$ **small firm scale** $\rightarrow$ indivisibility binds for the individual firm

- *This paper*: firms overcome the indivisibility **collectively**

  - document existence of inter-firm **rental market** for indivisible capital goods
  - quantify gains from rental market and study role of policy interventions

- Key messages of our study:

  1. role of clusters: firm-to-firm interactions widen the **firm boundary**
  2. policy effectiveness: leverage **market interactions** between firms

Technology Adoption and Indivisibilities

- Why technology does not flow to poor countries?

  - technology often embedded in **indivisible** capital goods (e.g. machines)
  - do indivisibilities hinder technology adoption and productivity?

  $\Rightarrow$ **small firm scale** $\rightarrow$ indivisibility binds for the individual firm

- *This paper*: firms overcome the indivisibility **collectively**

  - document existence of inter-firm **rental market** for indivisible capital goods
  - quantify gains from rental market and study role of policy interventions

- Key messages of our study:

  1. role of clusters: firm-to-firm interactions widen the **firm boundary**
  2. policy effectiveness: leverage **market interactions** between firms

Overview

- Novel **survey** of 1,000 manufacturing firms in urban Uganda
  - representative of three sectors: carpentry, metal fabrication and grain milling
  - information on entire production process for key products

- Use the data to uncover **key facts** about production
  1. many small firms side by side producing similar products
  2. economies of scale due to indivisible investment in high-capacity machines
  3. inter-firm **rental market** for machines → **achieve scale collectively**

- Equilibrium **model** of mechanization choices and machine rentals
  - measurement tool to estimate size of wedges and lab for counterfactuals

  (i) gains in mkt rev: no rent to frictionless: +45%; no rent to observed: +32%
  (ii) policy targeting: credit subsidies to renters vs owners [in progress]

Overview

- Novel **survey** of 1,000 manufacturing firms in urban Uganda
  - representative of three sectors: carpentry, metal fabrication and grain milling
  - information on entire production process for key products

- Use the data to uncover **key facts** about production
  1. many small firms side by side producing similar products
  2. economies of scale due to indivisible investment in high-capacity machines
  3. inter-firm **rental market** for machines $\rightarrow$ **achieve scale collectively**

- Equilibrium **model** of mechanization choices and machine rentals
  - measurement tool to estimate size of wedges and lab for counterfactuals

  (i) gains in mkt rev: no rent to frictionless: +45%; no rent to observed: +32%

  (ii) policy targeting: credit subsidies to renters vs owners [in progress]

Overview

- Novel **survey** of 1,000 manufacturing firms in urban Uganda
  - representative of three sectors: carpentry, metal fabrication and grain milling
  - information on entire production process for key products

- Use the data to uncover **key facts** about production
  1. many small firms side by side producing similar products
  2. economies of scale due to indivisible investment in high-capacity machines
  3. inter-firm **rental market** for machines $\rightarrow$ **achieve scale collectively**

- Equilibrium **model** of mechanization choices and machine rentals
  - measurement tool to estimate size of wedges and lab for counterfactuals

  (i) gains in mkt rev: no rent to frictionless: +45%; no rent to observed: +32%

  (ii) policy targeting: credit subsidies to renters vs owners [in progress]

Overview

- Novel **survey** of 1,000 manufacturing firms in urban Uganda
  - representative of three sectors: carpentry, metal fabrication and grain milling
  - information on entire production process for key products

- Use the data to uncover **key facts** about production
  1. many small firms side by side producing similar products
  2. economies of scale due to indivisible investment in high-capacity machines
  3. inter-firm **rental market** for machines $\rightarrow$ **achieve scale collectively**

- Equilibrium **model** of mechanization choices and machine rentals
  - measurement tool to estimate size of wedges and lab for counterfactuals

  (i) gains in mkt rev: no rent to frictionless: +45%; no rent to observed: +32%
  (ii) policy targeting: credit subsidies to renters vs owners [in progress]

Contribution to the Literature

1. Large literature on constraints that keep firms small
   [Banerjee Duflo '14; Ackgit et al '16; Hardy McCasland '17; Jensen Miller '18]
   - we should look also beyond individual firm size since **boundaries are wide**

2. Literature on fixed costs and poverty traps
   [Banerjee Duflo '05; Kaboski Townsend '11; Foster Rosenzweig '17; Balboni et al '19]
   - we highlight role of **inter-firm rental market** in overcoming indivisibility

3. Literature on firm clusters [Piore Sabel '84; Rabellotti '95; Schmitz '95]
   - we provide **quantitative assessment** and relevance for development policy

Plan of the Presentation

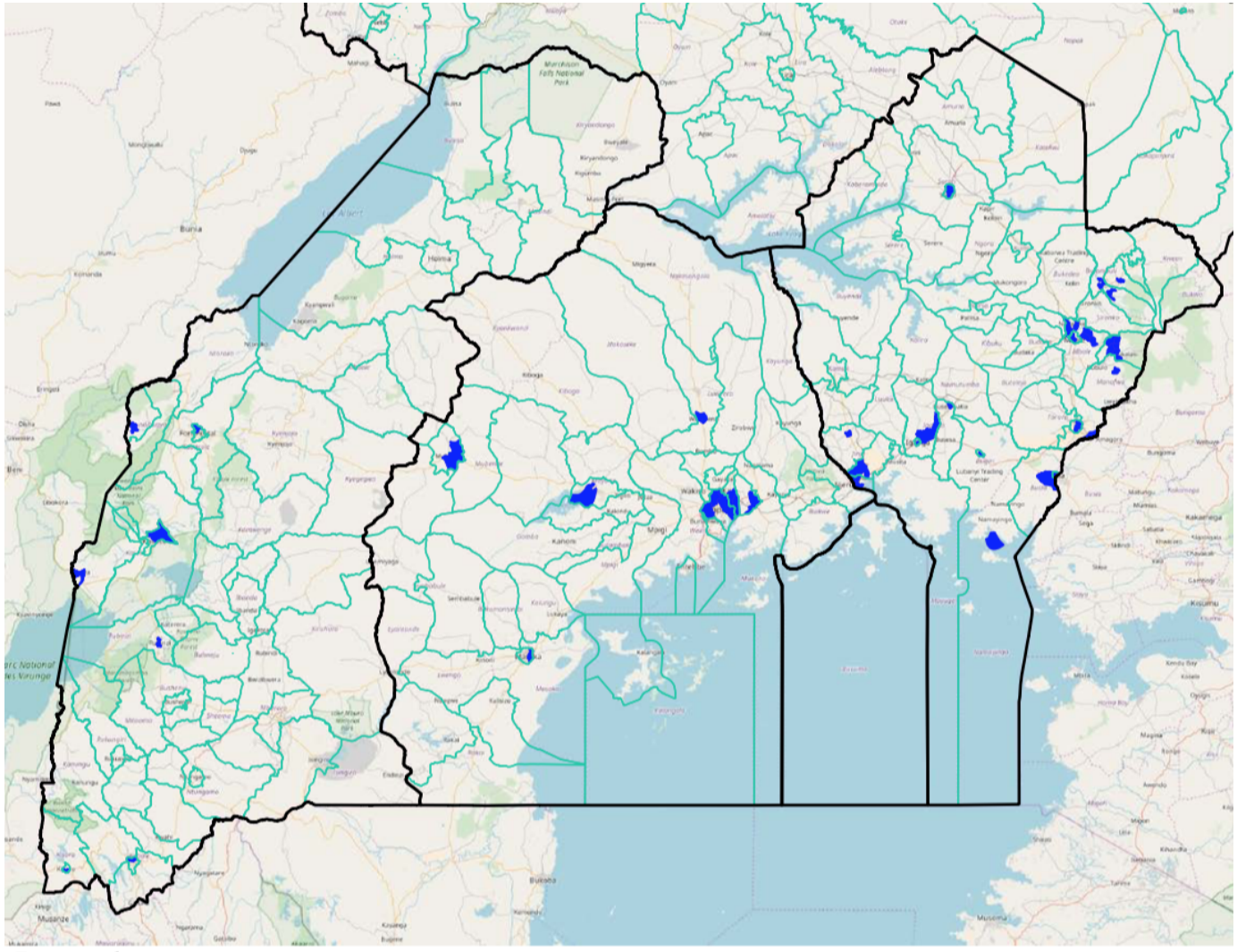
1. Survey

2. Key Facts on Production in Urban Uganda

3. Model

The Survey

Geographical Coverage



Final Firm Sample

	N. of Firms identified in listing	N. of Firms screened for survey eligibility in listing	N. of Firms selected for survey	N. of Firms interviewed in survey
	(1)	(2)	(3)	(4)
All sectors	**2,916**	**2,702**	**1,127**	**1,115**
Carpentry	1,487	1,381	518	516
Metal fabrication	1,171	1,092	441	433
Grain milling	258	229	168	166

Product-level Information

Production Steps Example

Step	Step Description	Typical Modern Machines	Typical Manual Tools
1	Design	Router	Hand drill
2	Drying the timber	Electric cylinder	
3	Cutting	Circular saw	Hand saw
4	Planing	Benchtop planer	Manual planer
5	Thicknessing	Thickness planer	Manual planer
6	Edging	Spindle moulder	Hand saw
7	Sanding	Disk sander	Sanding paper
8	Mortising	Drill	Hand drill
9	Finishing	Compressed air sprayer	Brush
10	Final Drying	Electric cylinder	

Difference b/w Modern Machines and Manual Tools

(a) Thickness Planer

(b) Manual Planer

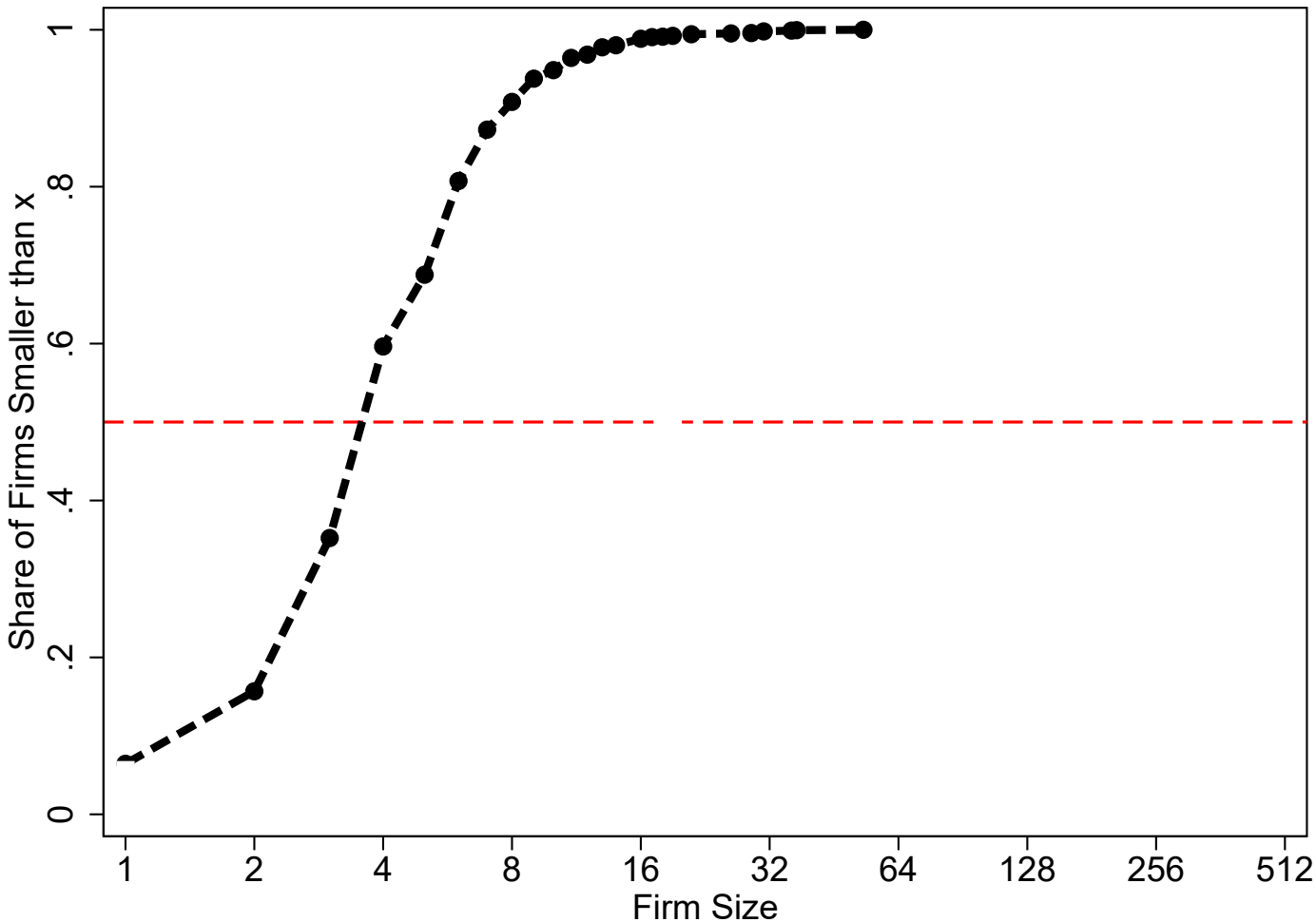
Key Facts on Production in Urban Uganda

Basic Firm and Worker Descriptives

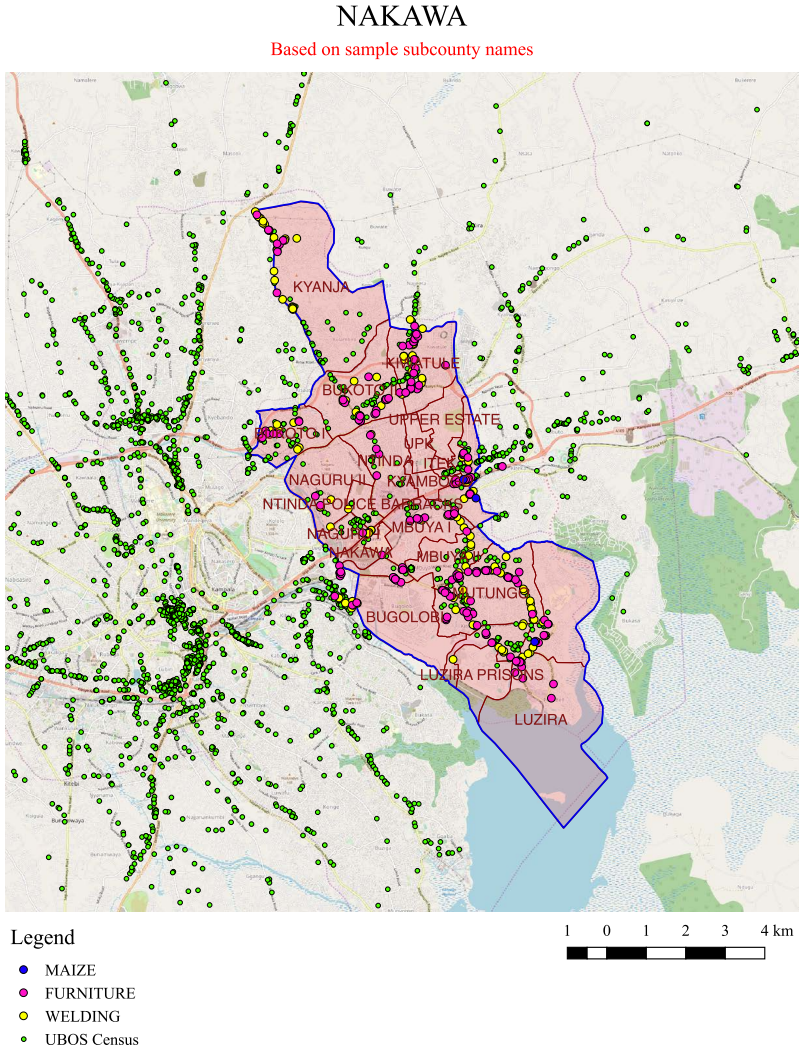
	All sectors
	(1)
Panel A: Firm characteristics	
Number of employees	4.7
Average monthly revenues (USD)	1,413.1
Average monthly profits (USD)	242.7
Average monthly profits per worker (USD)	45.5
Firm age (years)	9.9
Firm has trading licence (%)	82.2
Panel B: Owner characteristics	
Owner is male (%)	97.8
Owner age (years)	39.2
Owner years of education	9.9
Hours (usual) worked per day for the firm	9.4
Panel C: Employee characteristics	
Employee is male (%)	98.2
Employee age (years)	28.0
Employee years of education	9.4
Employee tenure (years)	3.5
Hours (usual) worked per day for the firm	9.8
Employee monthly wage (USD)	70.9

1. Many Small Firms Producing Similar Products

Median Firm is Small: Owner + 3 Employees

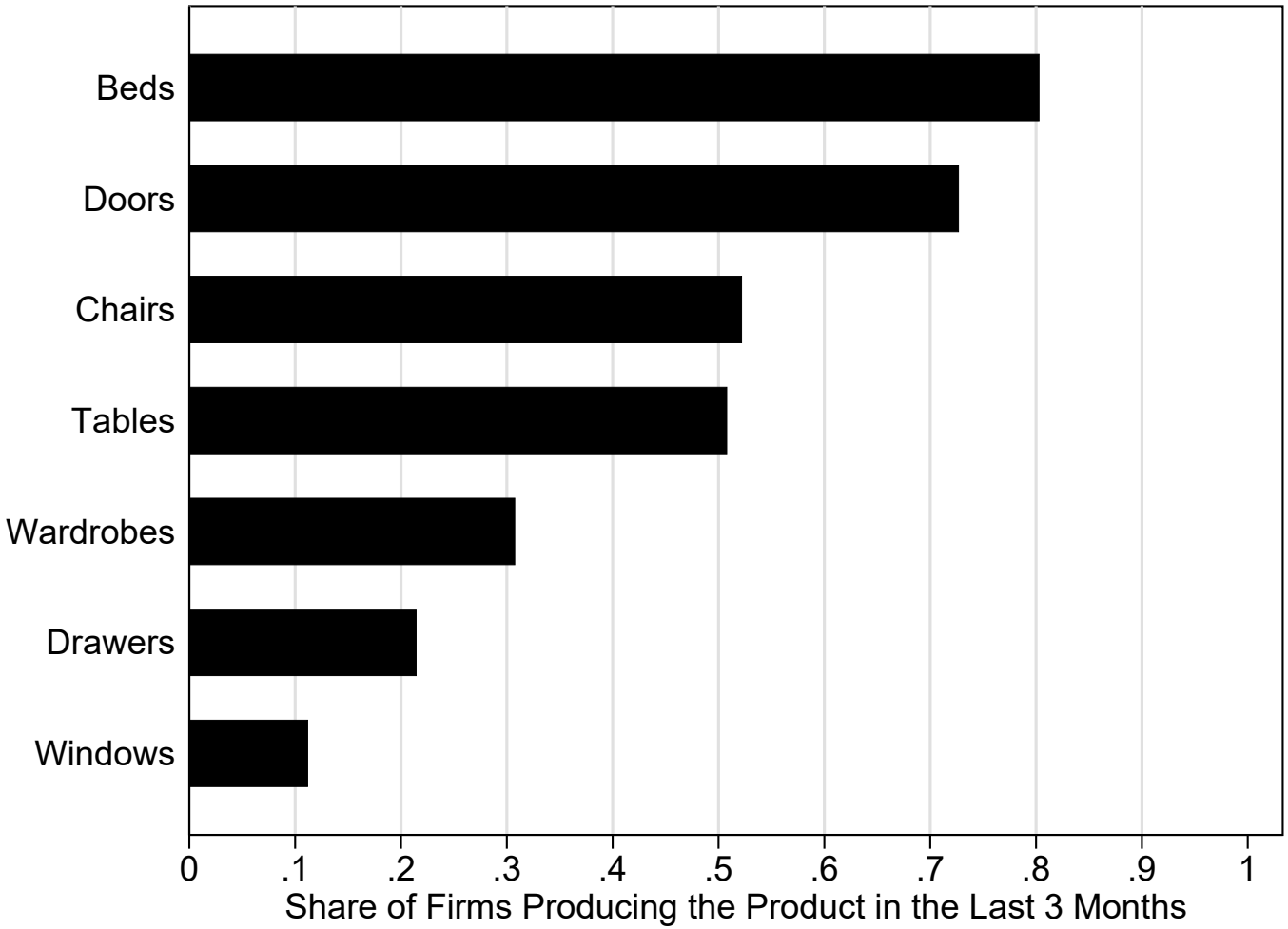


Many Small Firms within Close Distance



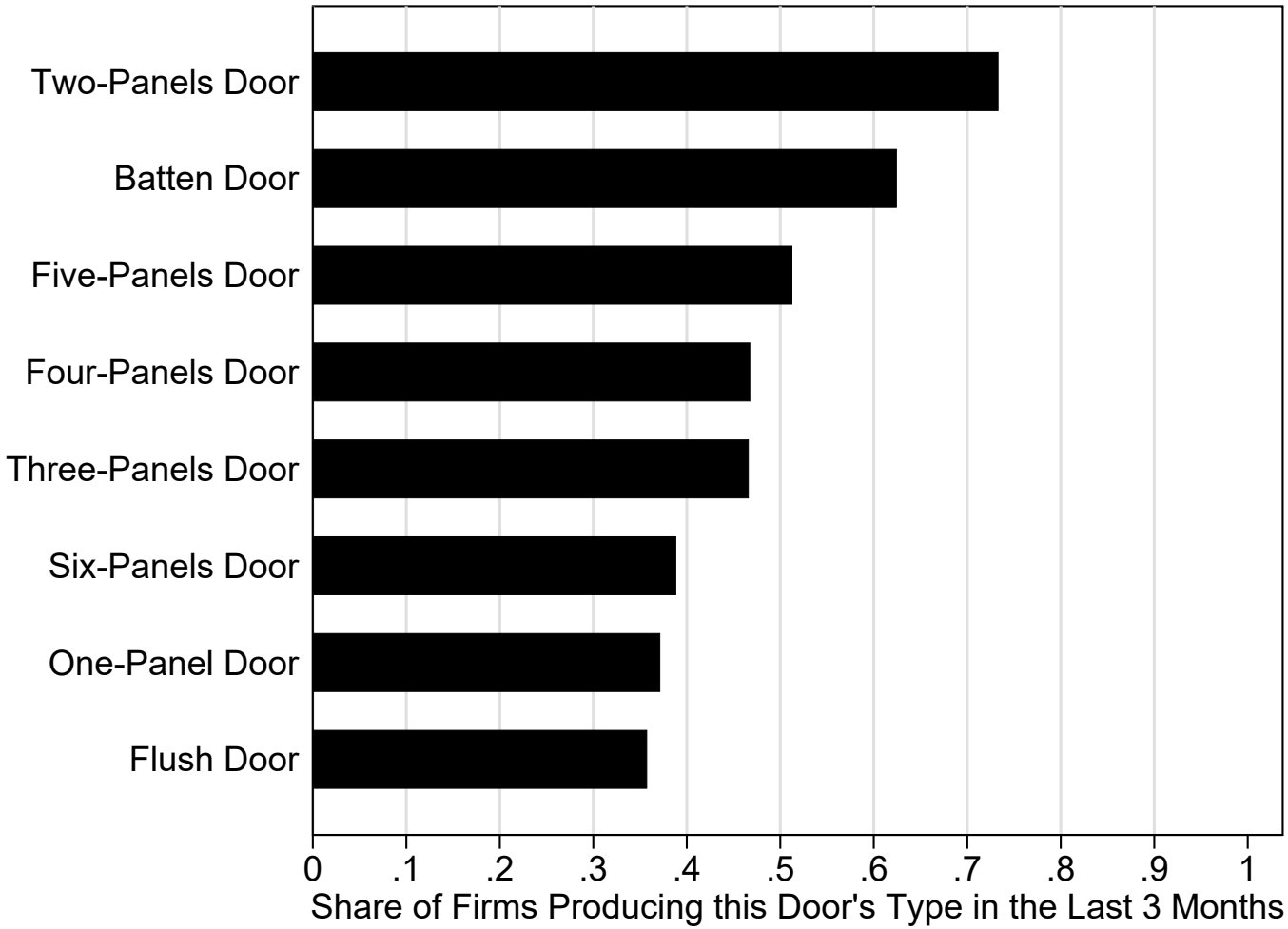
- Median number of firms within a 250m radius:
  - 4 firms in carpentry; 2 in metal products and 1 in grain milling

Firms Produce Similar Products (1)



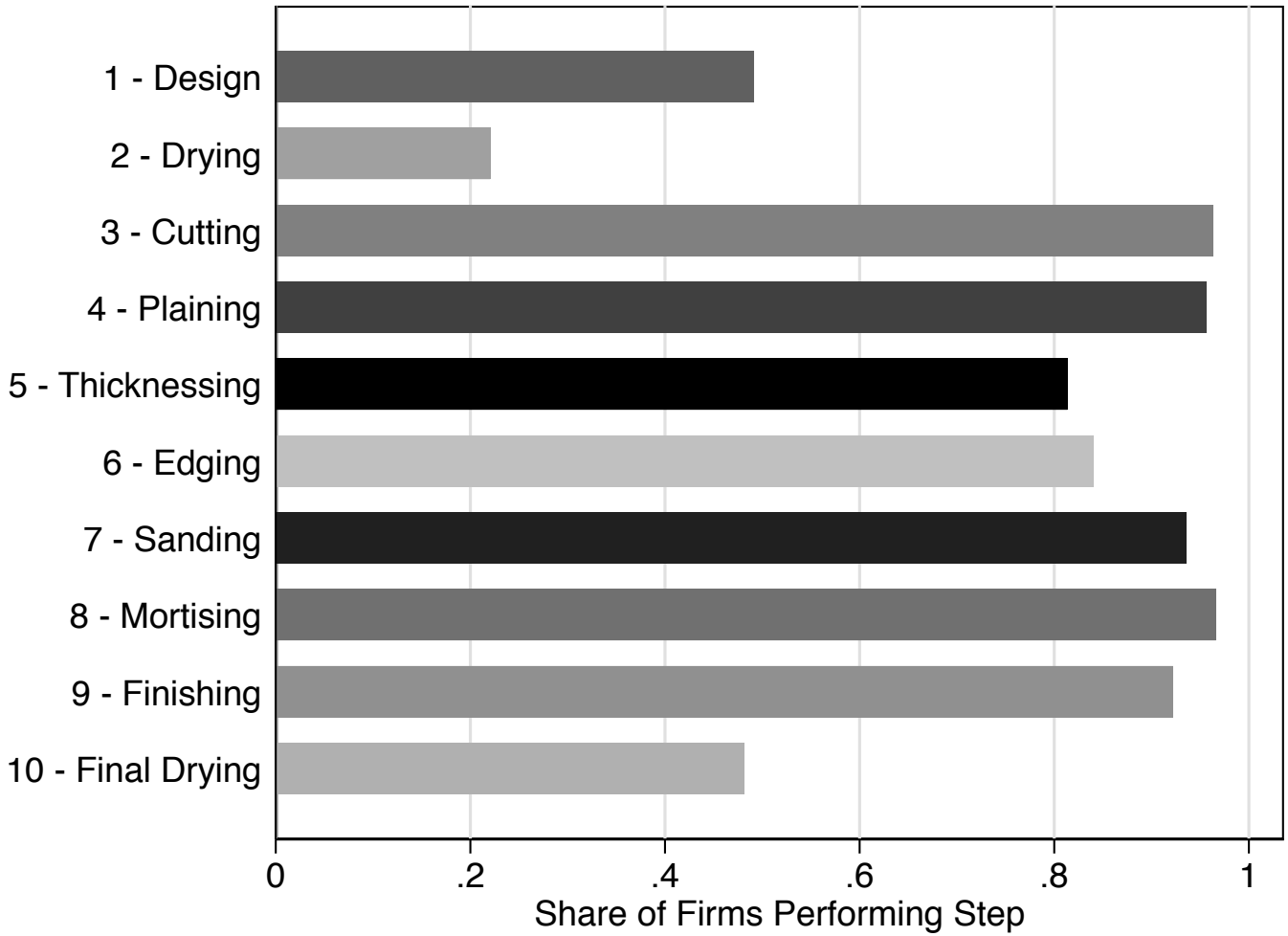
- Two-panel doors is our main product for carpentry (pre-specified)

Firms Produce Similar Products (2)



- Two-panel doors is our main product for carpentry (pre-specified)

Firms Follow Similar Production Steps



- Production steps are for two-panel doors and are pre-specified

2. Economies of Scale Due to Indivisibility of Machines

Machines: (i) Useful; (ii) Expensive; (iii) Large Capacity

- Modern machines allow to save labor time

  - e.g. thicknessing: 40 mins with thickness planer; 85 mins without it

  Time Reg Revenue Quantity Profit Variation

- Machines are expensive

  - average cost of thickness planers = \$4,280

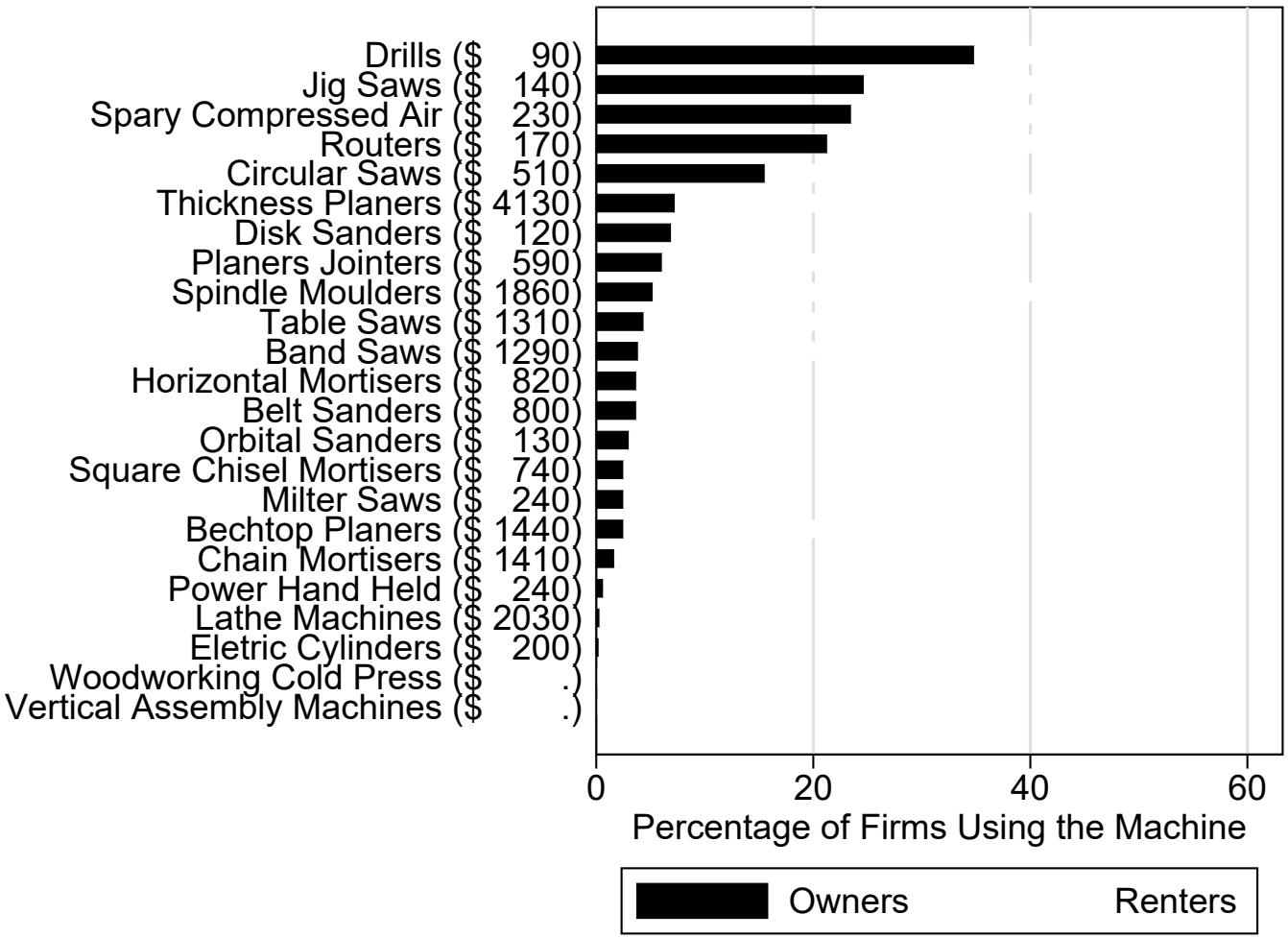
  - average cost of spindle moulders = \$2,180

  - median monthly profits = \$125

- Machines have high capacity for the typical firm

  - firms on average use any given machine for 9 hours per week
  (statistic calculated conditional on the firm using the machine)

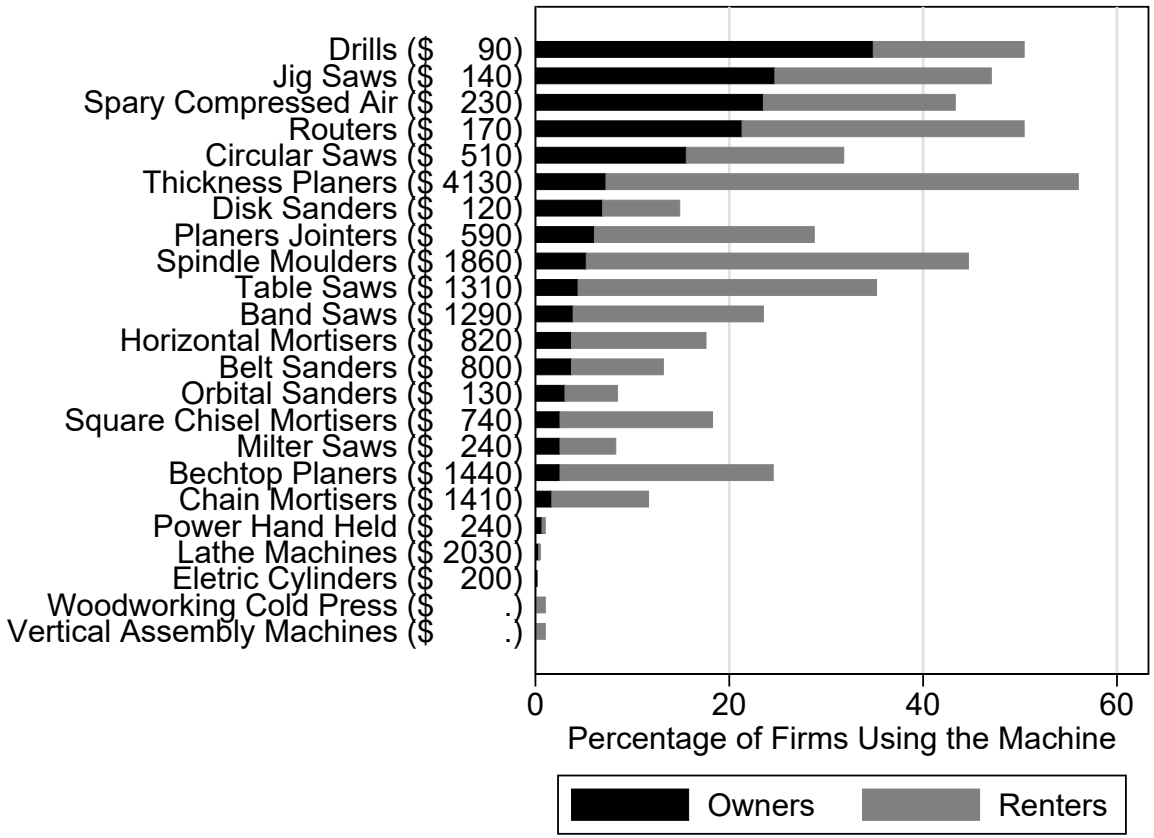
High Capacity & Price ⇒ Few firms Own Machines



- Unexploited economies of scale?

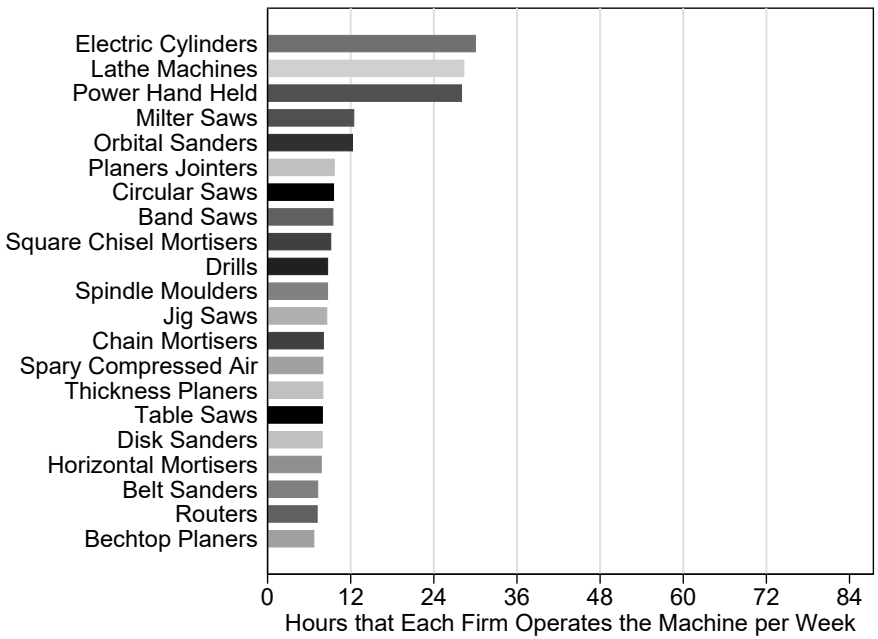
3. Rental Market for Machines

Most Firms Access Machines Through Rentals



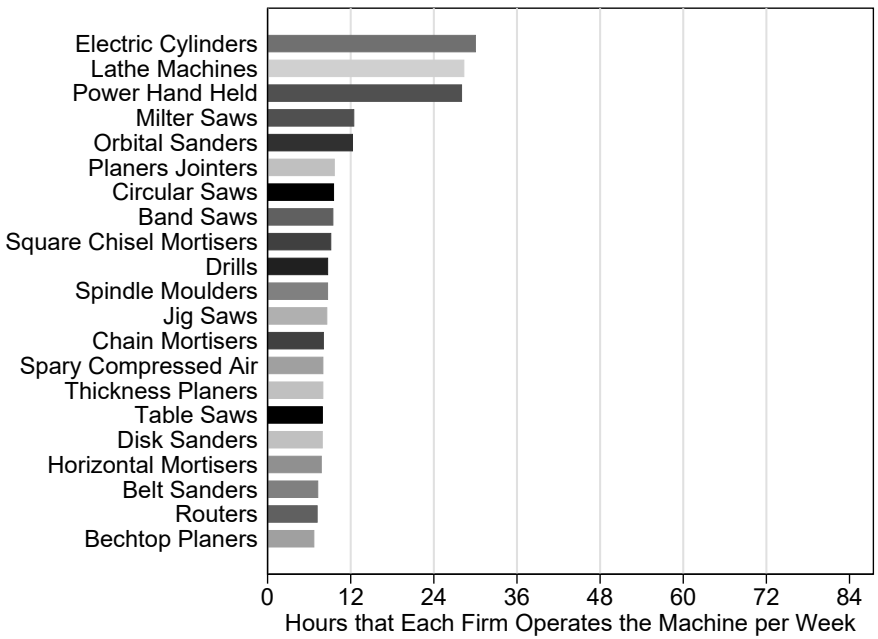
- Rentals: (i) mostly from other firms; (ii) used at owner premises
- Larger (more expensive) machines more likely to be rented OwnRent

Rentals Dramatically Increase Capacity Utilization

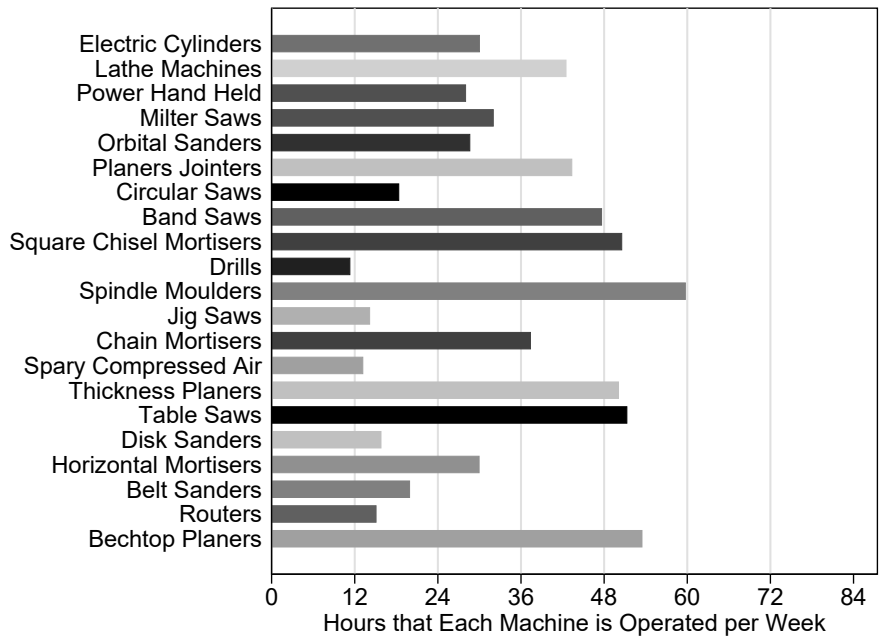


(c) Firm level

Rentals Dramatically Increase Capacity Utilization



(e) Firm level



(f) Market level

- Still sizeable "slack" in the capital input even after rentals [Egger et al 2019]
- Note: Market level capacity is imputed exploiting representativeness of our data

An Efficient Sharing Economy?

- Economies of scale driven by indivisibility of capital input
- Rental market ⇒ firms achieve scale collectively (partly)
- To what extent does rental mkt limit costs of small scale?

  - we need to measure the *wedges* associated with rental mkt

  - *wedges:* reduced form representation of both frictions and technology

  e.g. transportation costs, coordination costs, trust/moral hazard etc

⇒ Model for: theory, quantification, counterfactuals, and policy

An Efficient Sharing Economy?

- Economies of scale driven by indivisibility of capital input
- Rental market ⇒ firms achieve scale collectively (partly)
- To what extent does rental mkt limit costs of small scale?
  - we need to measure the *wedges* associated with rental mkt
  - *wedges:* reduced form representation of both frictions and technology

  e.g. transportation costs, coordination costs, trust/moral hazard etc

⇒ Model for: theory, quantification, counterfactuals, and policy

Additional Results Help Motivate the Model

- No evidence of scale economies driven by labor [Labor]
  1. weak link between size and labor organization within the firm
  2. labor is more expensive at firms with higher sales
  3. labor market frictions are an important constraint

  [Bassi and Nansamba '19, Hardy and McCasland '17]

- Imperfect competition in output market [Demand]
  1. firms produce slightly differentiated products
  2. demand is segmented: most sales to nearby customers [Jensen Miller '18]

- Limited concentration in machine ownership [Concentration]
  1. result holds even within firm cluster
  2. suggests limited monopoly power of owners

Model

Environment

- Model a one-sector economy inhabited by managers
  - a manager is defined by a bundle (q, r): demand q; cost of capital r
  - managers choose how to produce to maximize profits
- Production function requires to complete $x \in [0, 1]$ steps
  - Leontief across steps; w/i steps: (i) mechanization choice; (ii) (k_x, l_x) choice

$$y = \min_{x \in [0,1]} \left\{ \max \left\{ \lambda_x l_x ; \mu_x k_x^{\alpha_x} l_x^{1-\alpha_x} \right\} \right\}$$

- Equilibrium rental market for capital inputs (machines)
  - each step has an associated machine, that can be either rented or bought
  - managers that buy machines decide how much to rent them out, given prices
  - rental market is in equilibrium, and subject to wedges

Manager Problem

- Manager problem can be divided into two components:
  1. choice of optimal firm size/output:

$$\max_{y} qy^{1-\eta} - c(y)$$

  2. choice of production methods and inputs to minimize cost of productio

$$\begin{aligned} c(y) &= \sum_{x \in \mathbb{X}} c_x(y) \\ c_x(y) &= \mathrm{E}\left[\min\left\{\underbrace{c_{l,x}(y)}_{\text{labor}}, \underbrace{c_{r,x}(y)}_{\text{rent}}, \underbrace{c_{o,x}(y)}_{\text{own}}\right\}\right] \end{aligned}$$

- Note: the discrete choice is smoothed out with Extreme Value Type I shocks

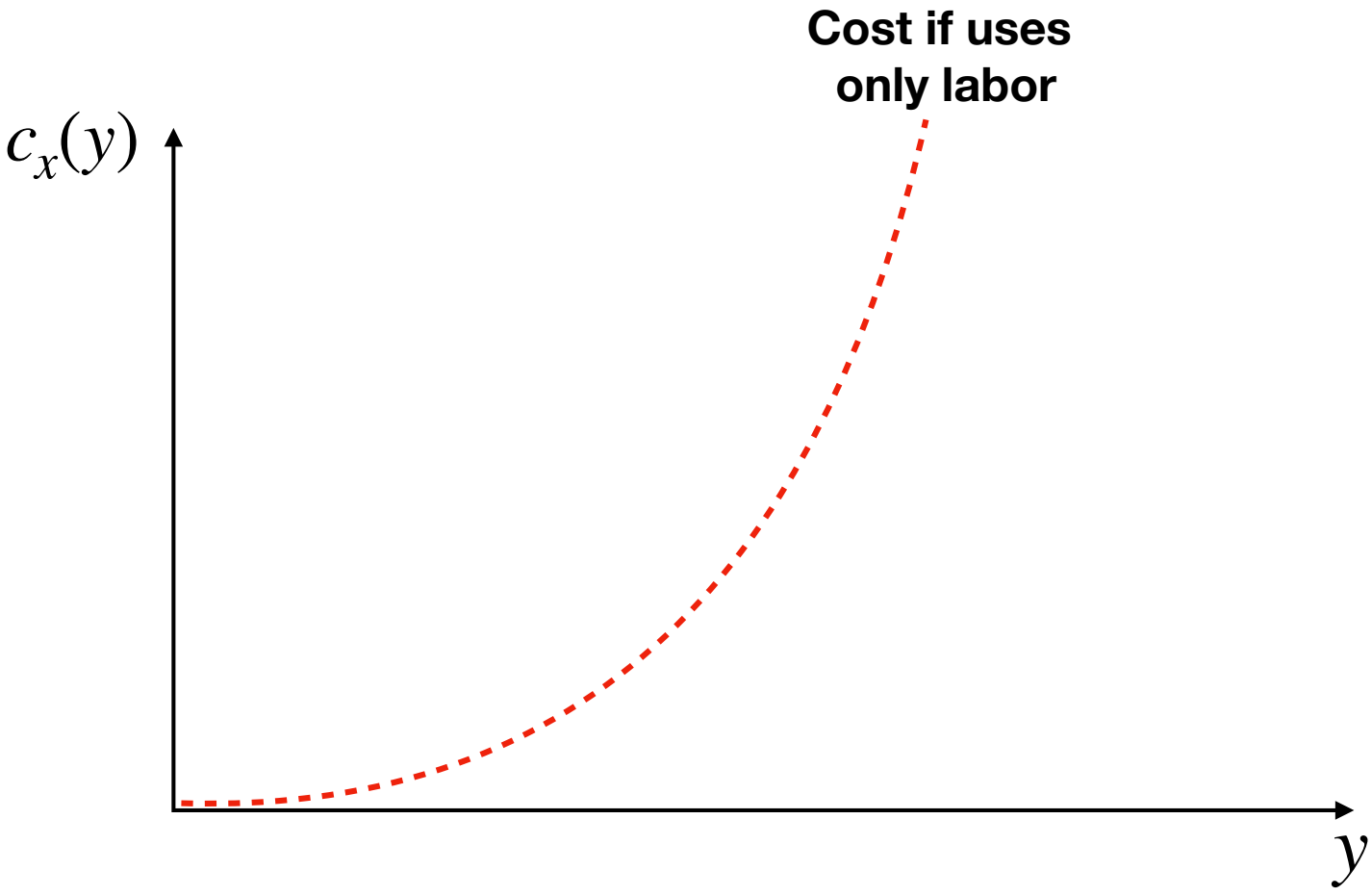
Cost of Producing Step x with Labor

- Cost function of managers that use only labor

$$c_{l,x}(y) = \underbrace{w y^{\omega}}_{\text{wage}} \times \underbrace{\lambda_x^{-1} y}_{\text{labor to produce } y}$$

- ω captures labor market frictions in reduced form
- w is wage level (in partial equilibrium)

Cost of Producing Step x with Labor



Cost of Producing Step x with Renting

- Cost function of capital renters

$$\begin{aligned} c_{r,x}(y) &= \min_{l_x, k_x} w y^{\omega} l_x + (1+\tau_x) p_{r,x} k_x \\ s.t. &\quad \mu_x l_x^{1-\alpha_x} k_x^{\alpha} \geq y \end{aligned}$$

Cost of Producing Step x with Renting

- Cost function of capital renters

$$\begin{aligned} c_{r,x}(y) &= \min_{l_x,k_x} w y^{\omega} l_x + (1+\tau_x) p_{r,x} k_x \\ s.t. &\quad \mu_x l_x^{1-\alpha_x} k_x^{\alpha} \geq y \end{aligned}$$

- Cost function for owner with a rental market

$$\begin{aligned} c_{o,x}(y) &= (r+\delta) p_{b,x} + \psi_x + \min_{l_x,k_x,C_x} w y^{\omega} l_x + \chi_x \frac{C_x^{1+\gamma_x}}{1+\gamma_x} - p_{r,x}(C_x - k_x) \\ s.t. &\quad \mu_x l_x^{1-\alpha_x} k_x^{\alpha} \geq y, \quad C_x \geq k_x \end{aligned}$$

Cost of Producing Step x with Renting

- **Minimized** cost function of capital renters

$$c_{r,x}(y) = \hat{\mu}_{r.x}^{-1} y^{1+(1-\alpha_x)\omega}$$

Cost of Producing Step x with Renting

- **Minimized** cost function of capital renters

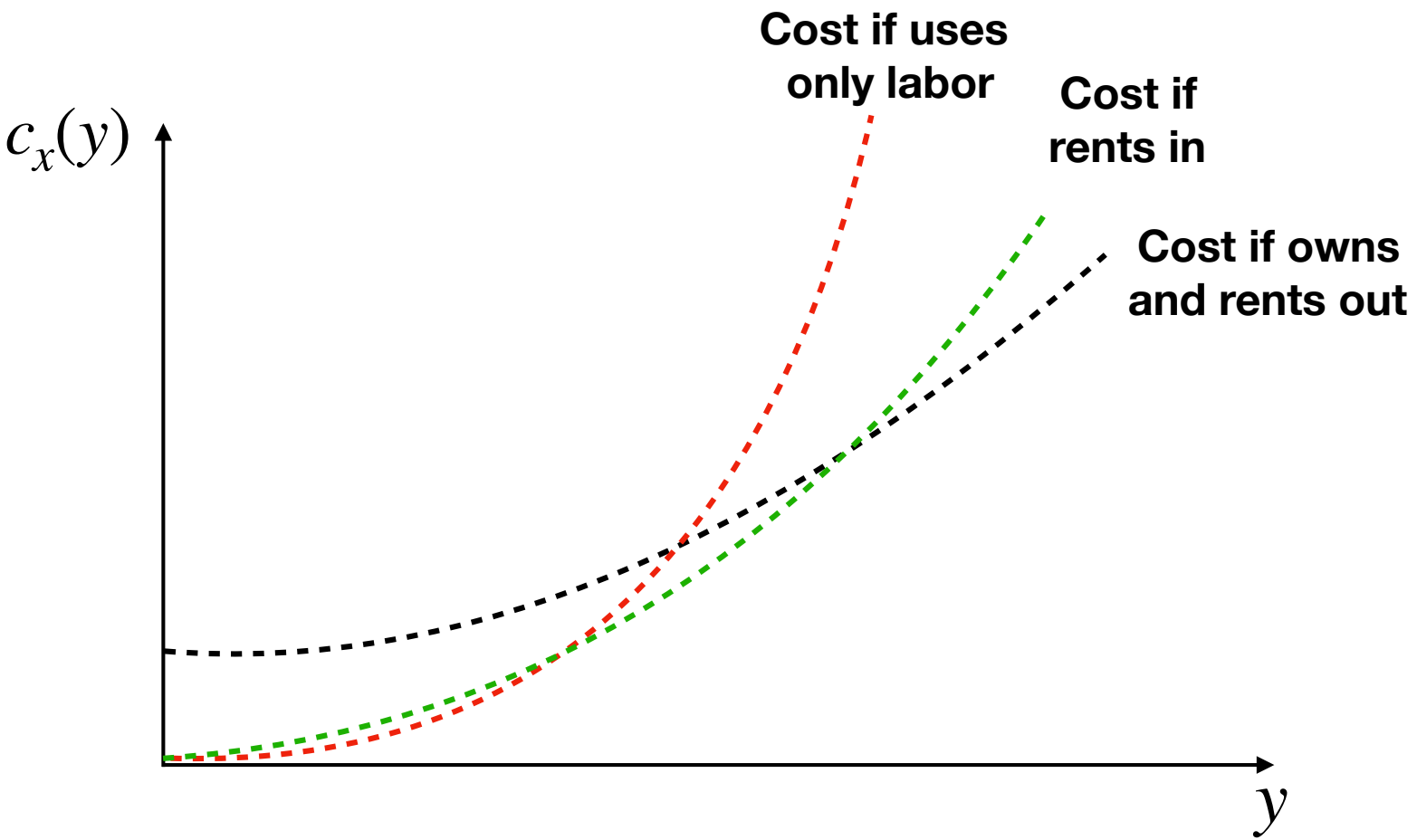
$$c_{r,x}(y) = \hat{\mu}_{r.x}^{-1} y^{1+(1-\alpha_x)\omega}$$

- **Minimized** cost function for owner with a rental market

$$c_{o,x}(y) = \underbrace{(r+\delta)\, p_{b,x} + \psi_x}_{\text{Fixed Cost}} - \underbrace{\prod}_{\text{Total Rental Value}} + \underbrace{\hat{\mu}_{o.x}^{-1} y^{1+(1-\alpha_x)\omega}}_{\text{Variable Cost}}$$

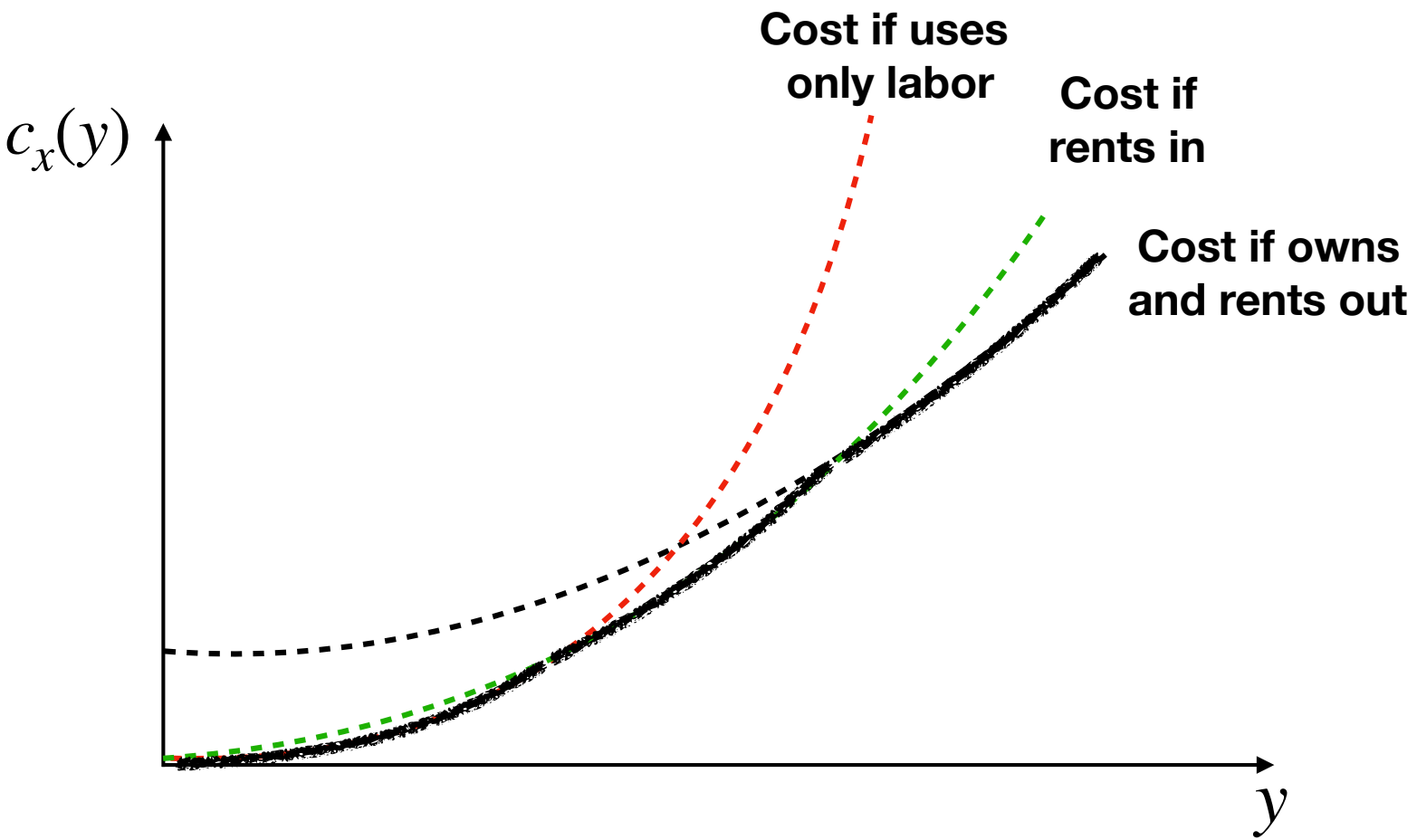
- where $\hat{\mu}_{r.x}^{-1} > \hat{\mu}_{o,x}^{-1} \rightarrow$ single-crossing properties

Mechanization choice of Step x, with Renting



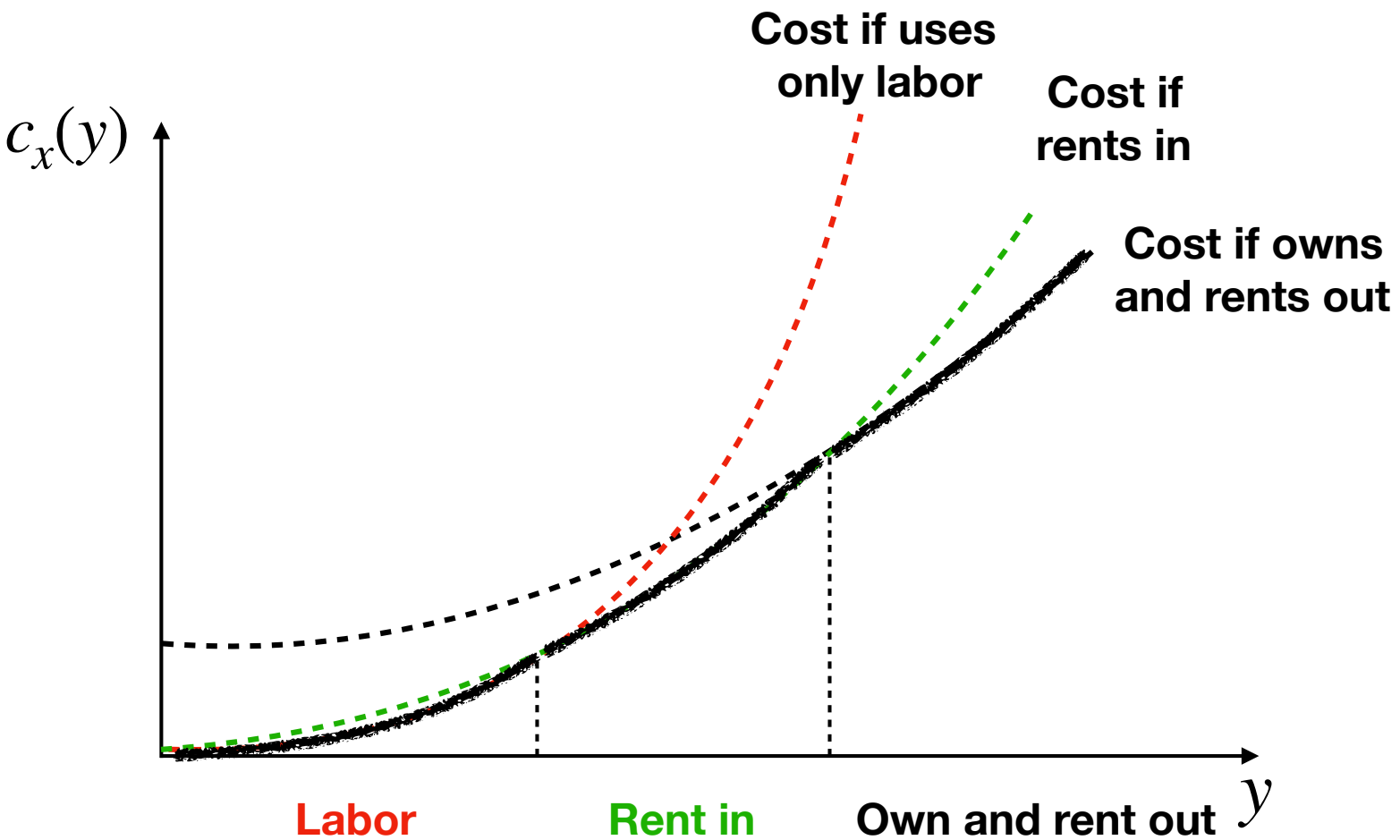
Equilibrium

Mechanization choice of Step x, with Renting



Equilibrium

Mechanization choice of Step x, with Renting



Equilibrium

Bringing the Model to Data

Model to Data: Three Core Insights

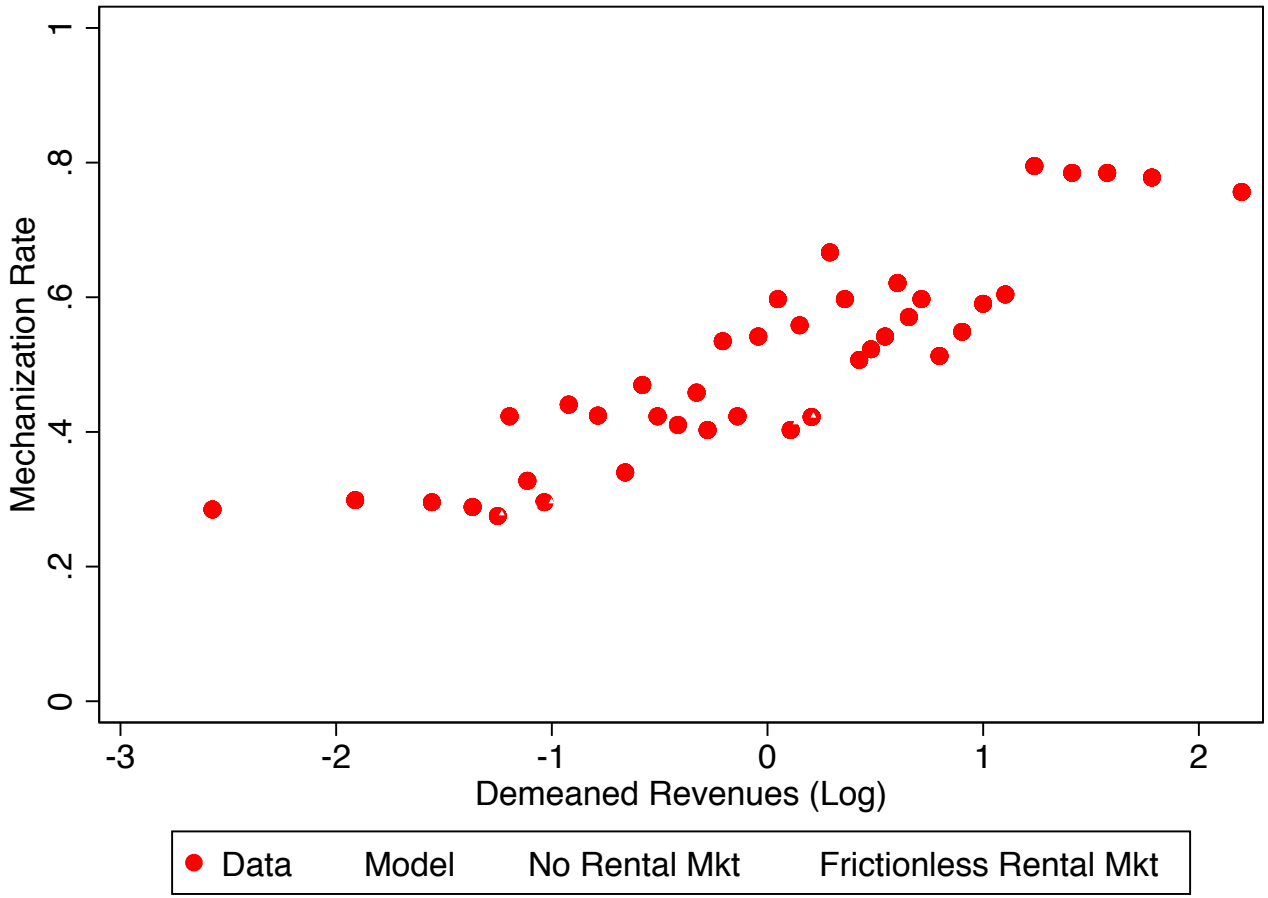
1. Functional forms + rich data → calibration of most parameters
   - model is rich, but only few parameters are estimated w/i model structure

2. Capital-labor ratios of renters and owners maps into wedge τ_x
   - renters marginal cost is $(1+\tau_x)\, p_{r,x}$. owners opportunity cost is $p_{r,x}$
   - step level regression across firms gives $\tau_x \sim 0.3$

Wedge

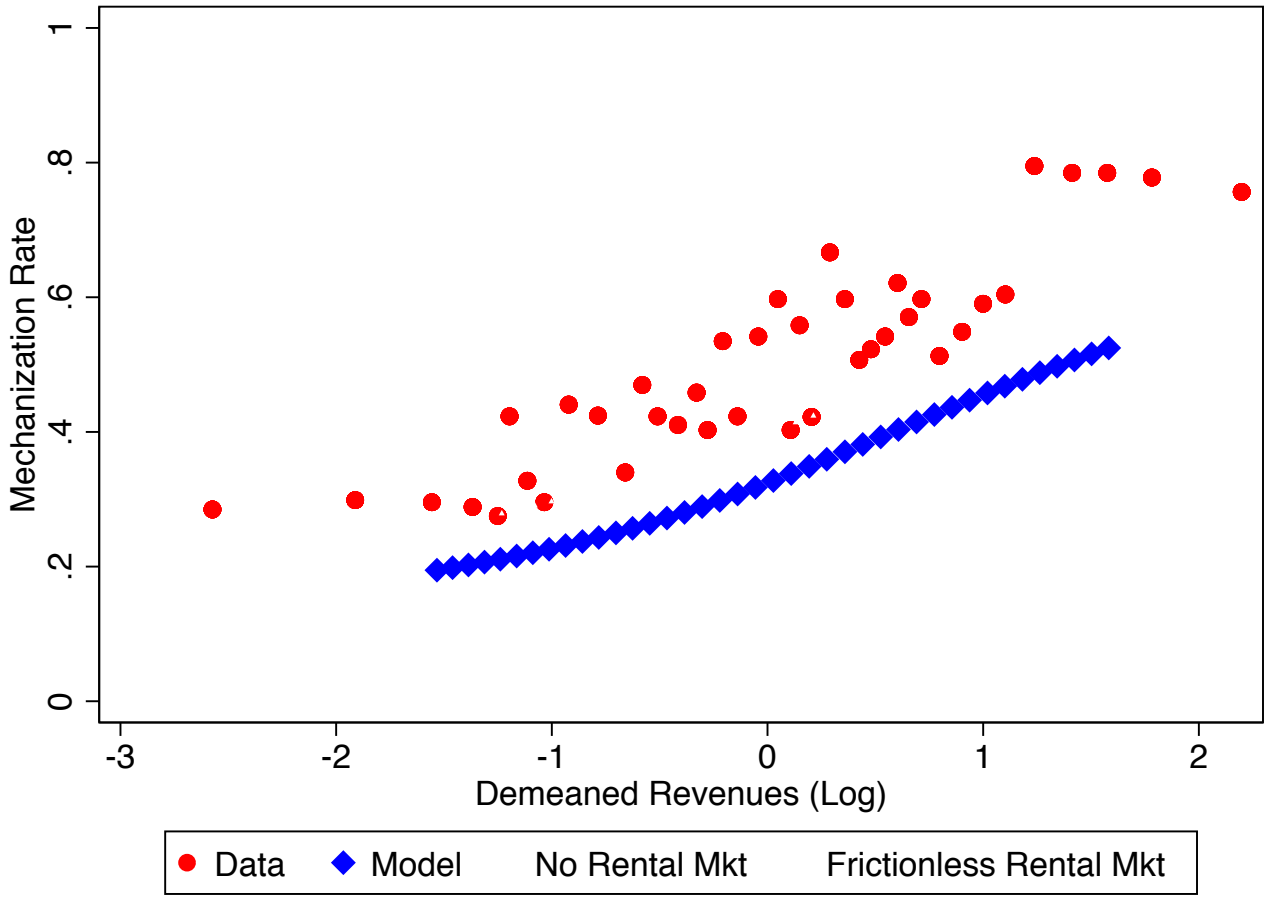
3. We observe the eq. $p_{r,x} \rightarrow$ recover the cost ψ_x that clears market
   - supply of machine time in rental market decreases in ψ_x

Main Targeted Moments



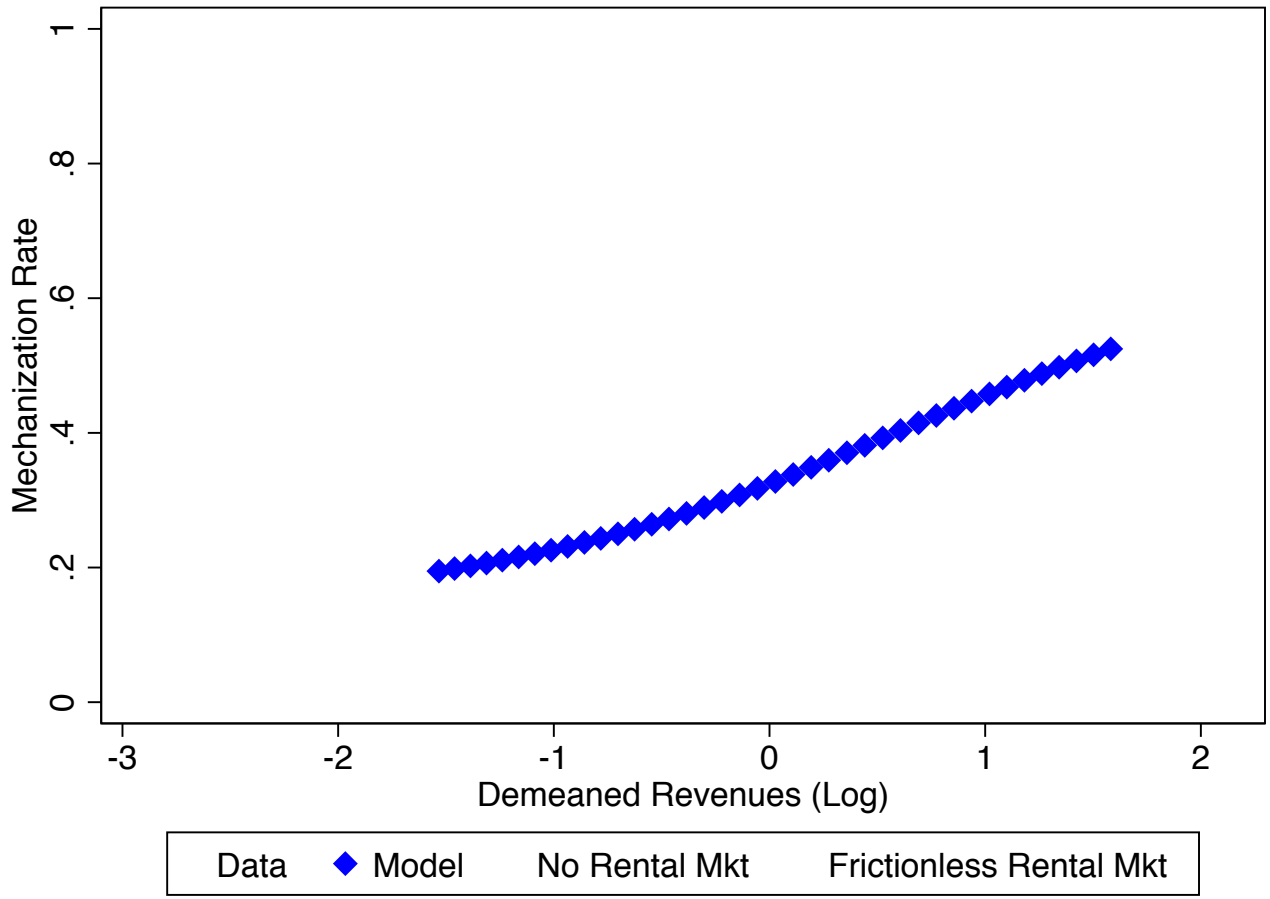
Four moments jointly targeted: i) av. mechanization rate; ii) correlation w/ revenues; iii) variance of revenues; iv) machines' capacity utilization (not in figure)

A (Very!) Preliminary Model's Estimation

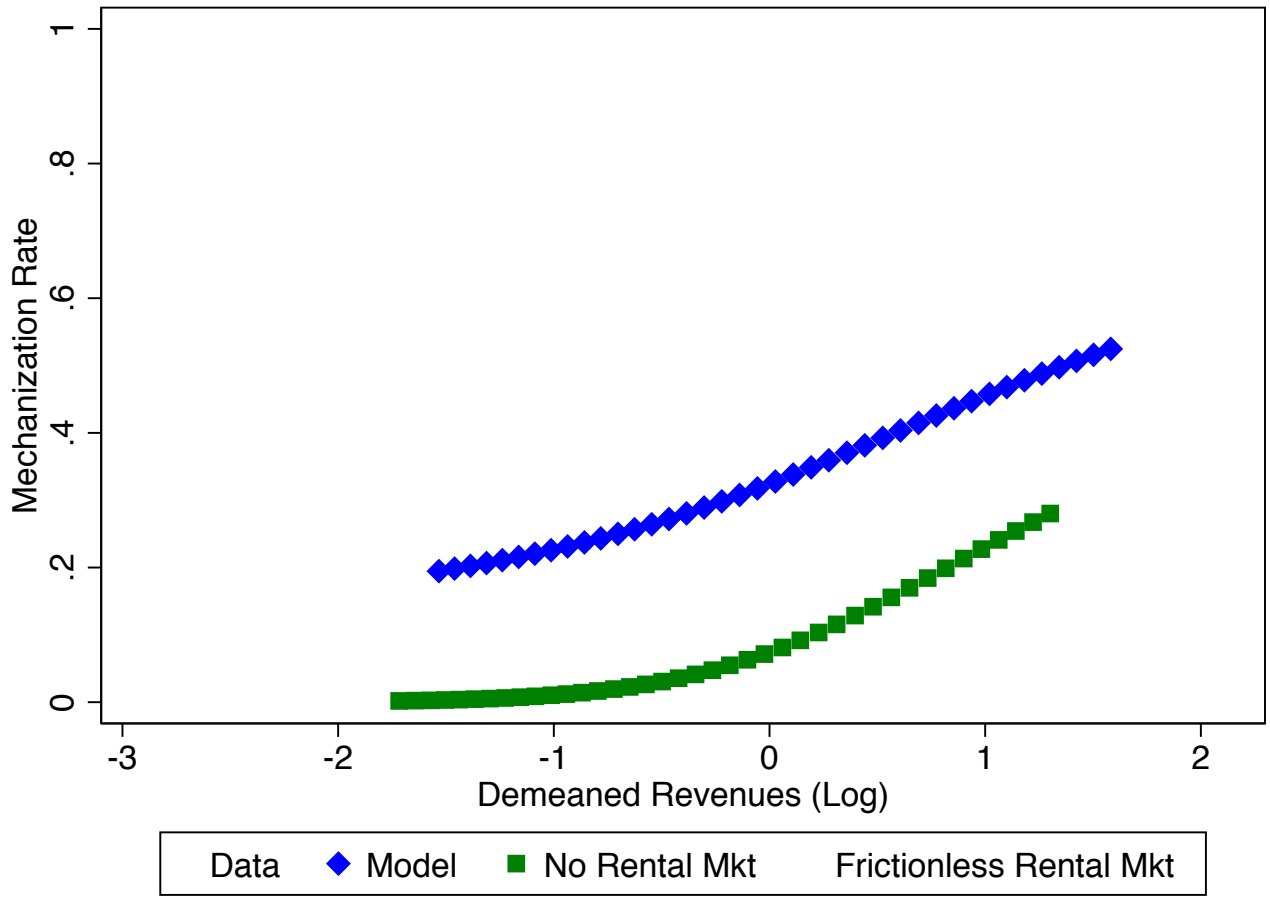


Notes: i) PF w/ one step only; ii) 3 parameters estimated by SMM: 1. cost shocks; 2. mean of q; 3. var of q; iii) all others are exactly identified from model restrictions

1^{st} Counterfactual: Shut Down the Rental Mkt

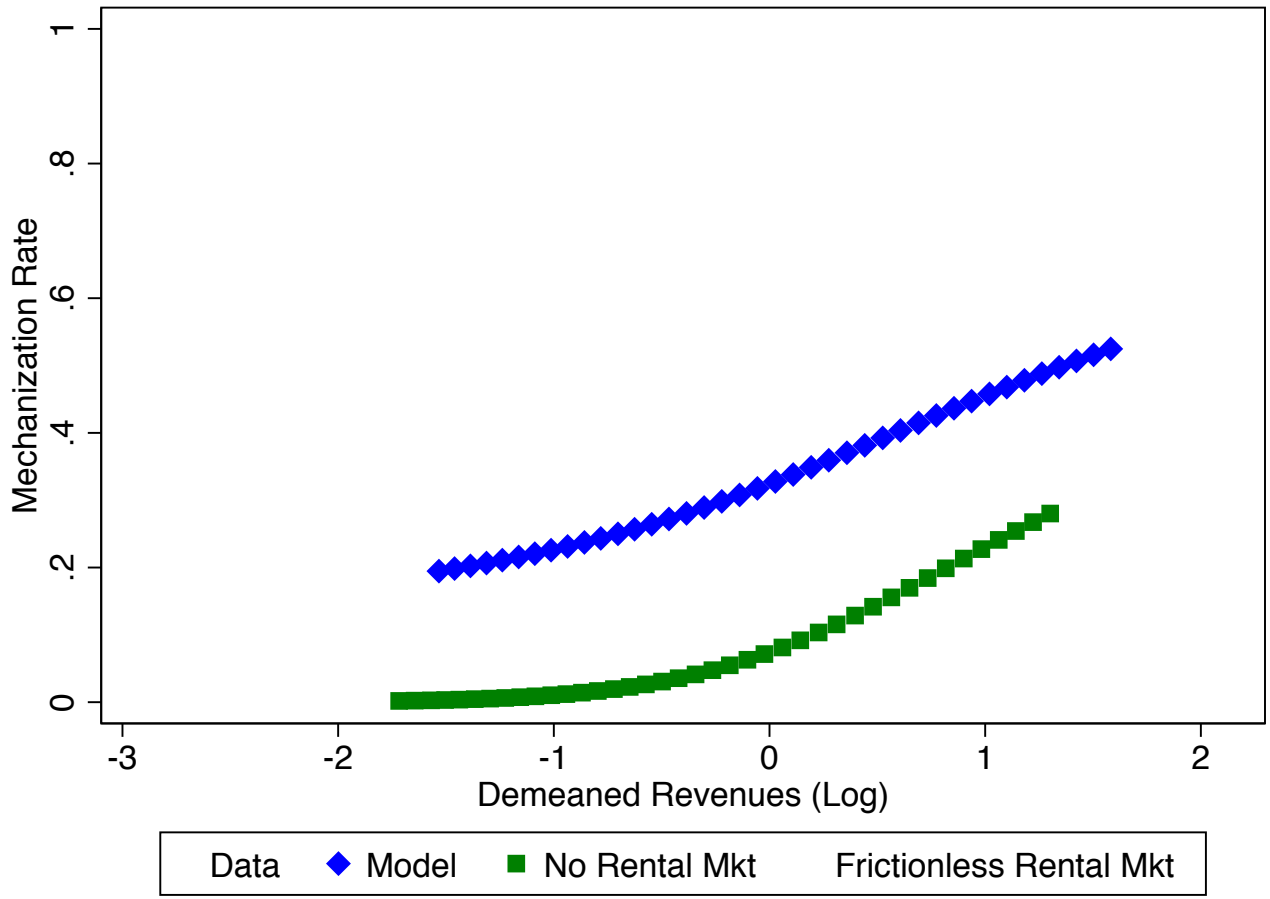


1^{st} Counterfactual: Shut Down the Rental Mkt

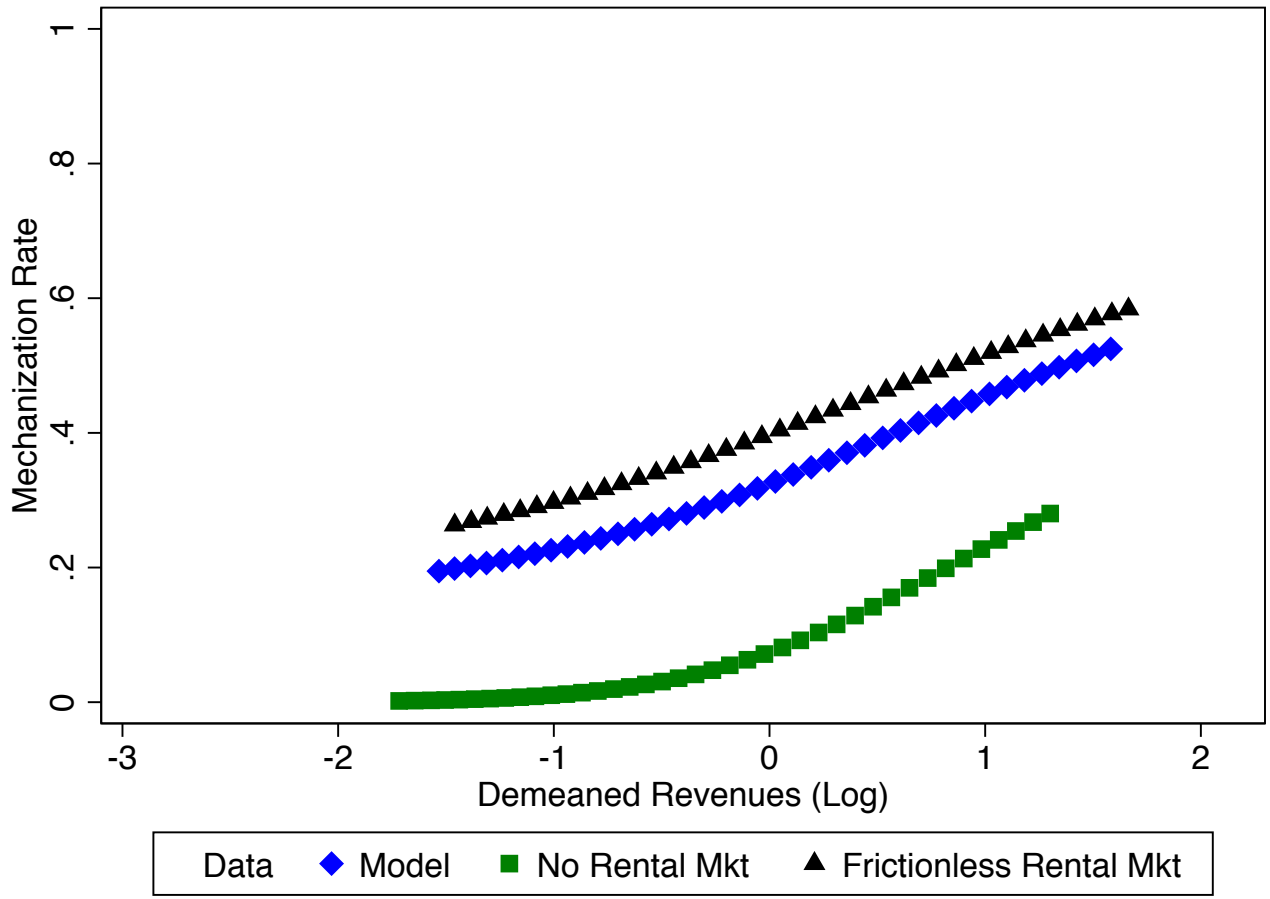


- Results: mechanization ⇓ by 2/3; revenues ⇓ by 25%; labor productivity ⇓ by 19%
- Both large and small firms are hurt, but for different reasons

2^{nd} Counterfactual: Frictionless Rental Mkt ($\tau = 0$)



2^{nd} Counterfactual: Frictionless Rental Mkt ($\tau = 0$)



- Results: mechanization ⇑ by 15%; revenues ⇑ by 9%; labor productivity ⇑ by 6.5%
- In GE also lenders benefit, since they now charge a higher price

Conclusion

- This project: new survey + model to interpret the data

  $\rightarrow$ study role of economies of scale and indivisibilities for development

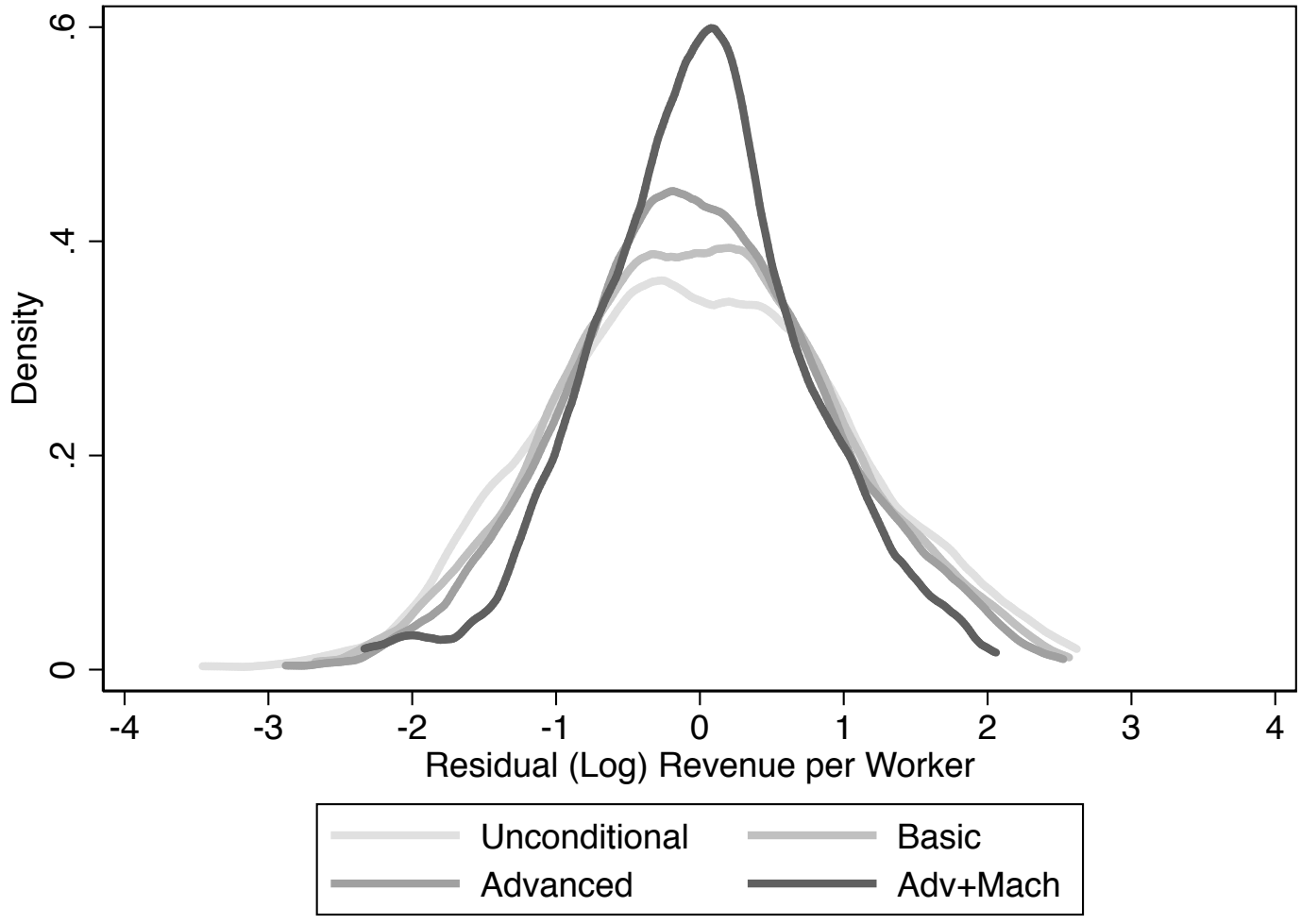
- Three key takeaways (so far):

  1. active rental mkt for machines $\rightarrow$ firm boundaries are wide
  2. wedges in the rental market are limited
  3. market revenues up 35% relative to no rental mkt case

- In progress: counterfactuals for policy targeting

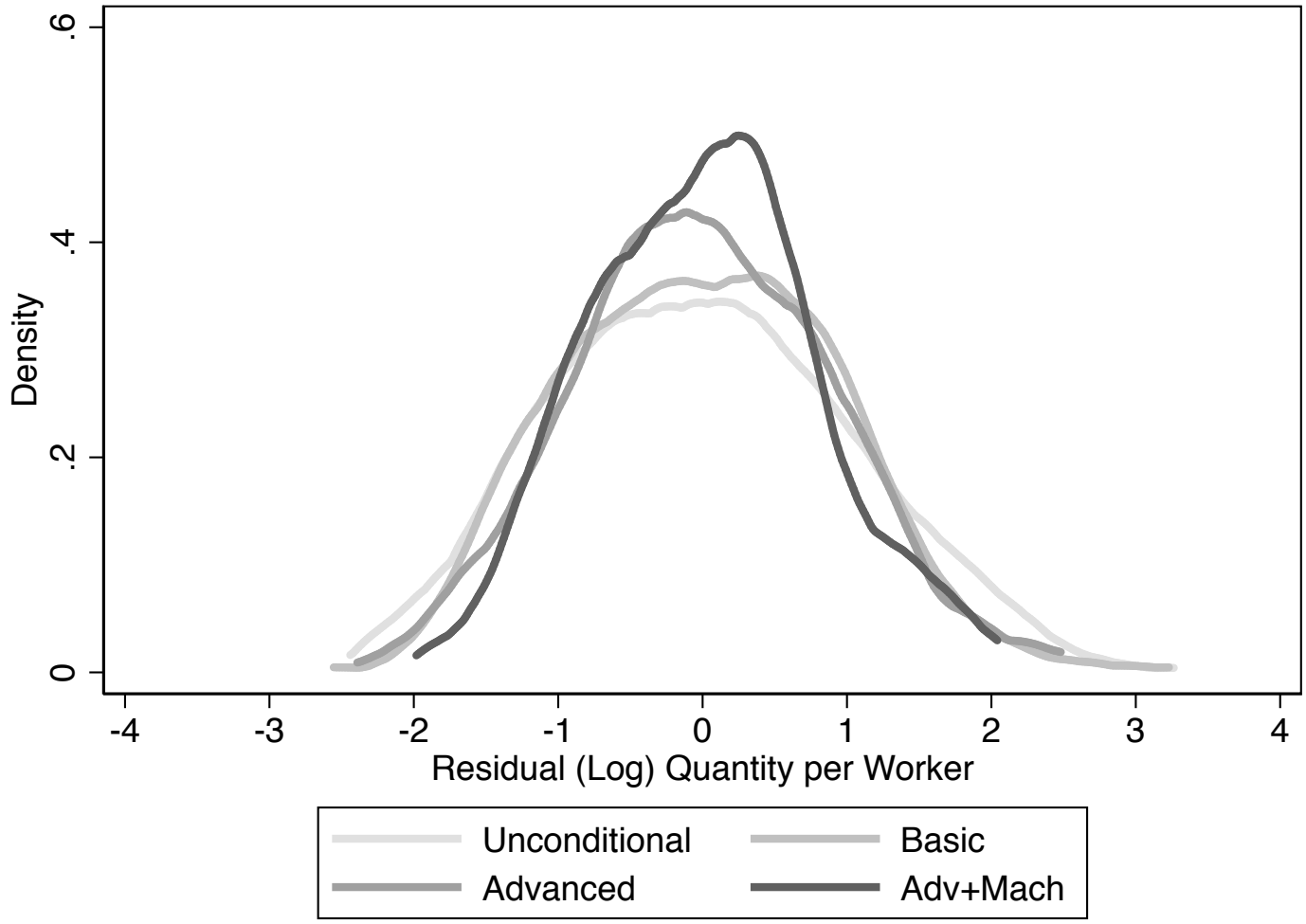
  - credit subsidies to renters vs owners

Explaining Dispersion in Revenues per Worker



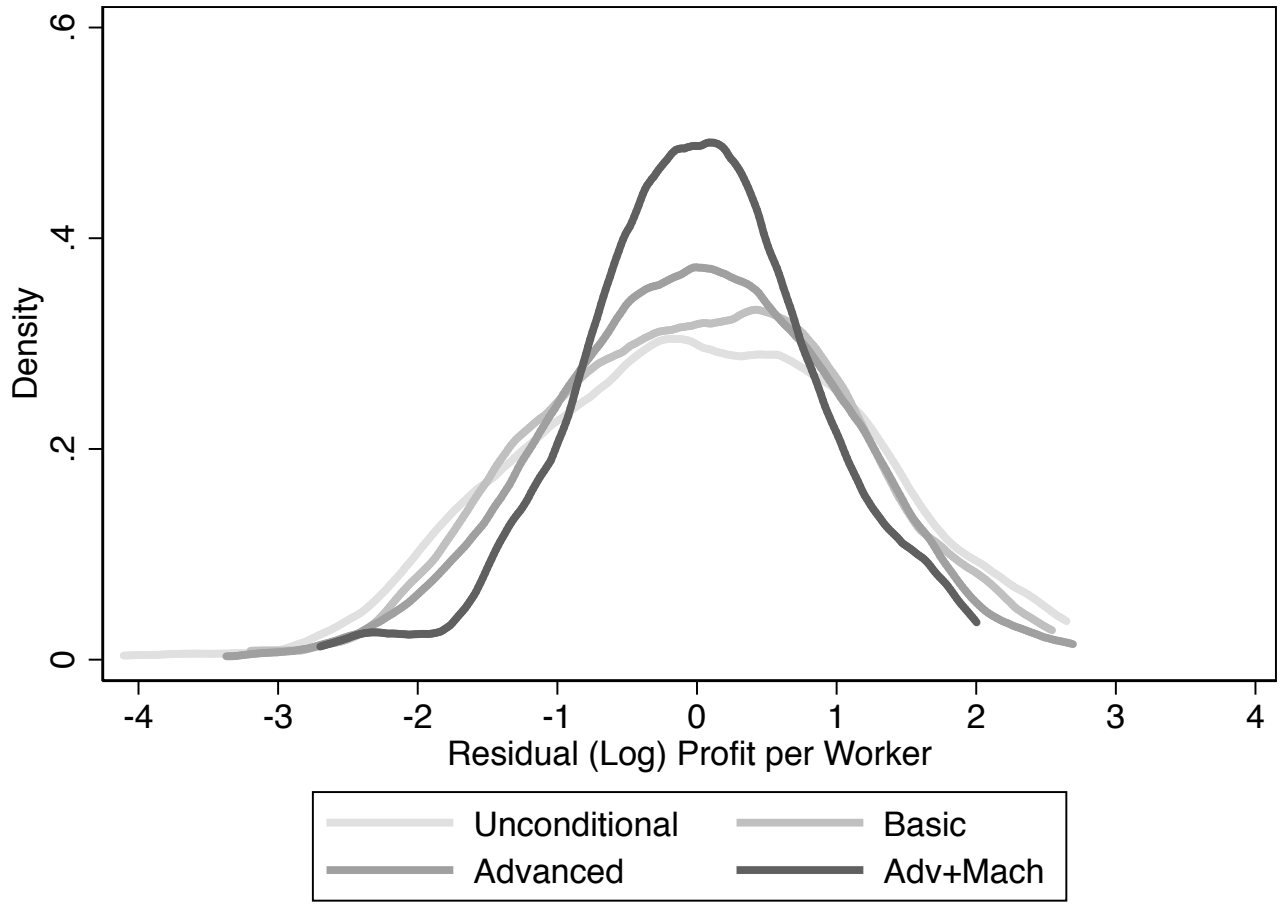
Back

Explaining Dispersion in Quantity per Worker



Back

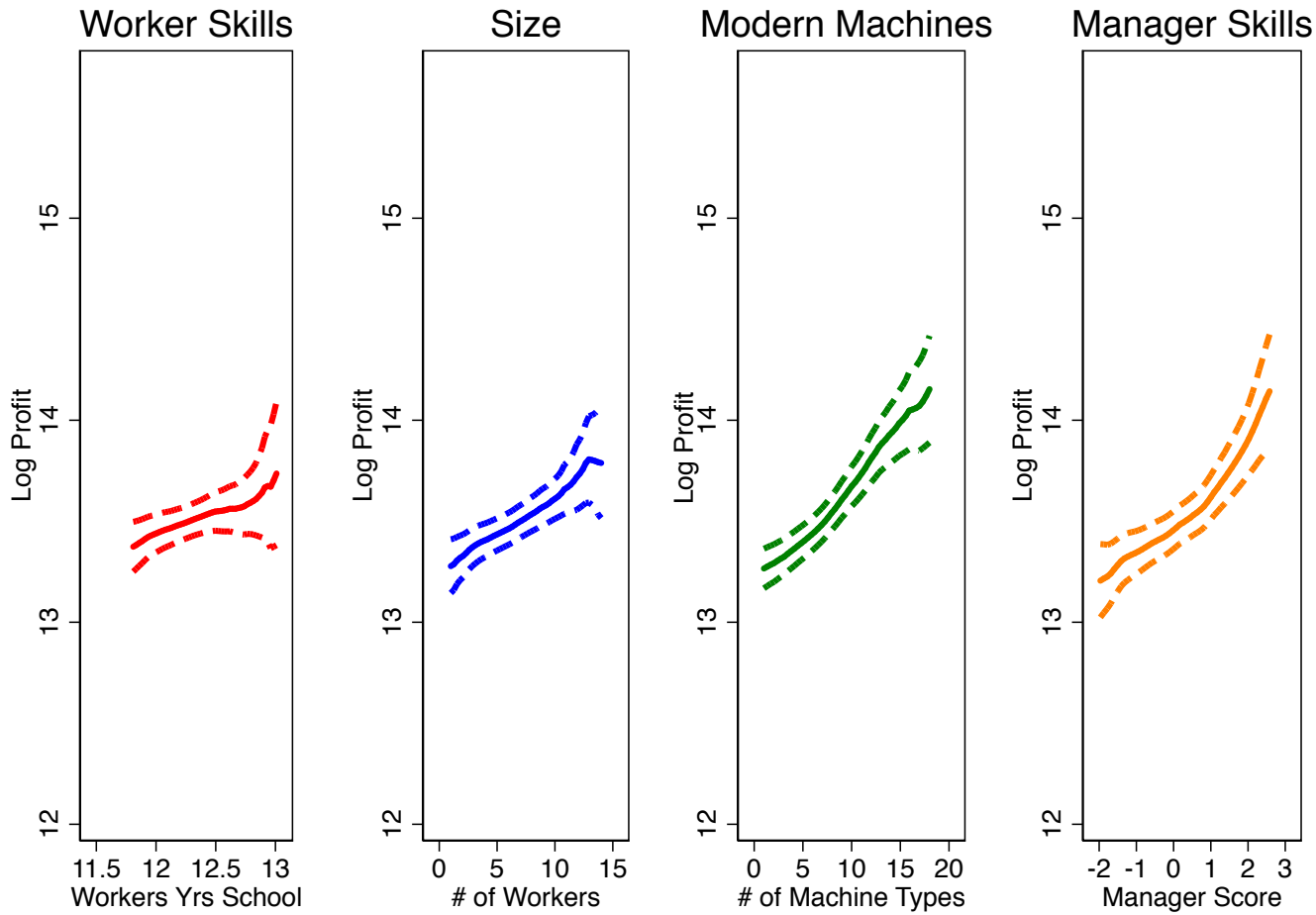
Explaining Dispersion in Profit per Worker



- 75/25 pct ratio: 2.85 (unconditional: 5.51; only machines: 3.41)
- 75/25 pct ratio of wages in US, controlling for Xs: 2.29

Back

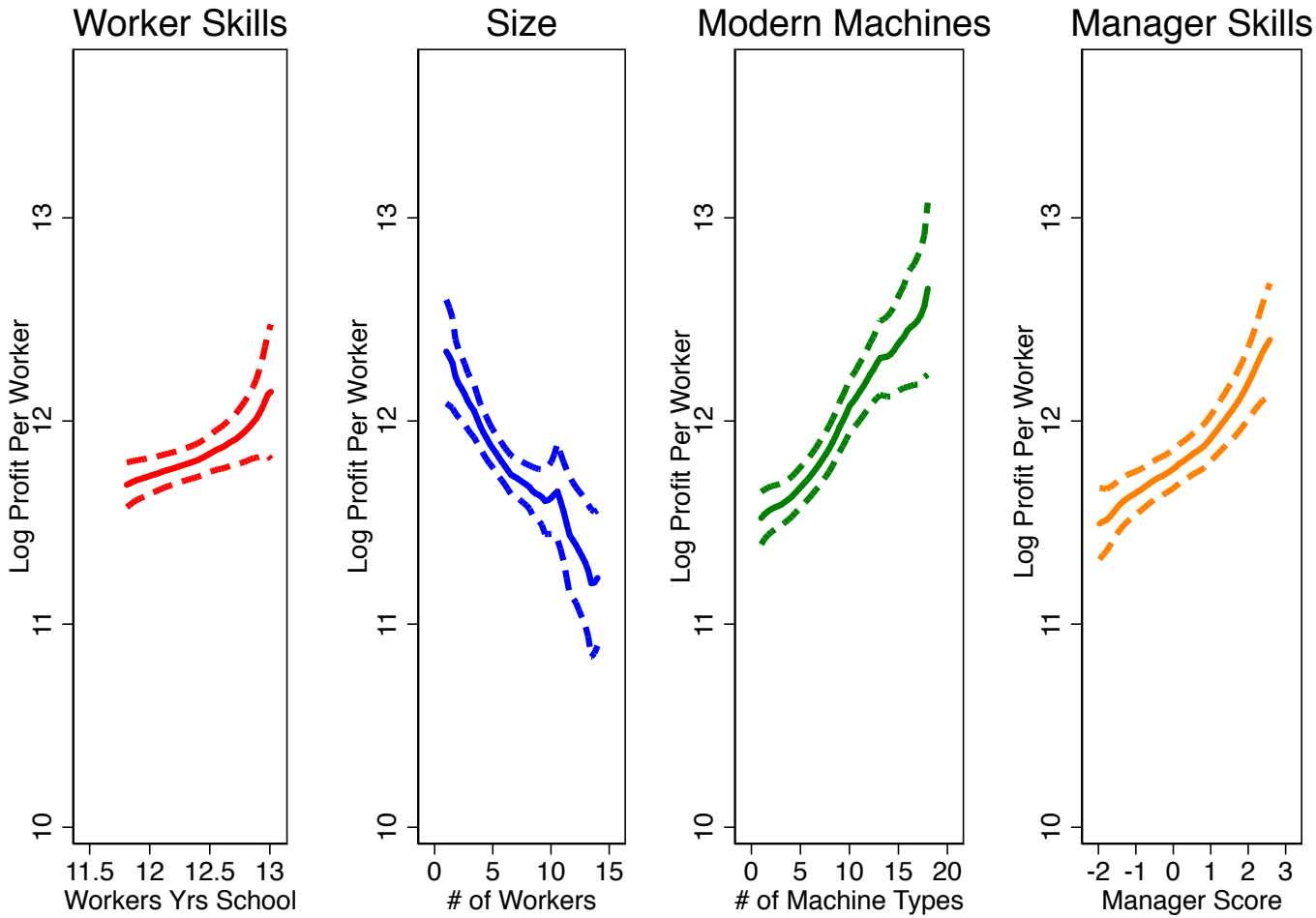
Key Correlates of Profitability Across Firms



- Controls for sub-county FEs
- Results robust to running LASSO

Per Worker Back

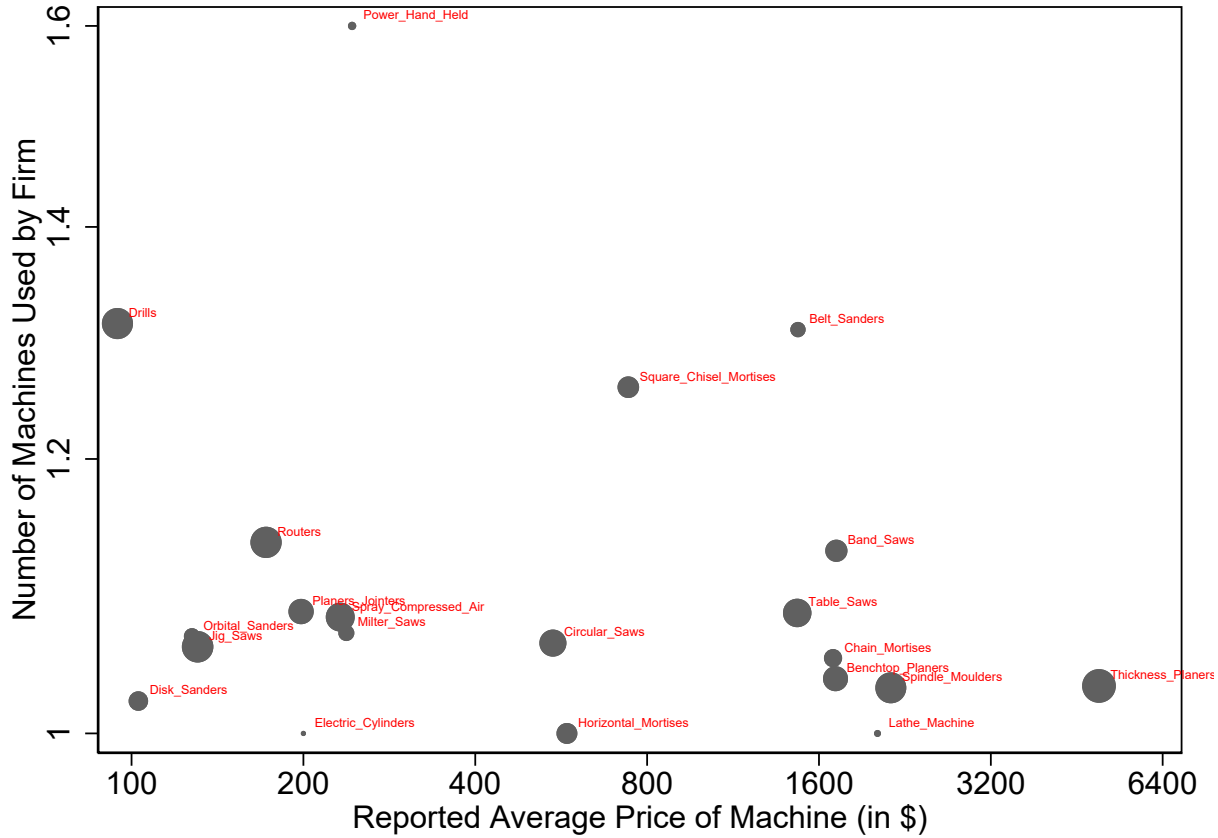
Key Correlates of Profitability Across Firms



- Controls for sub-county FEs
- Results robust to running LASSO

Back

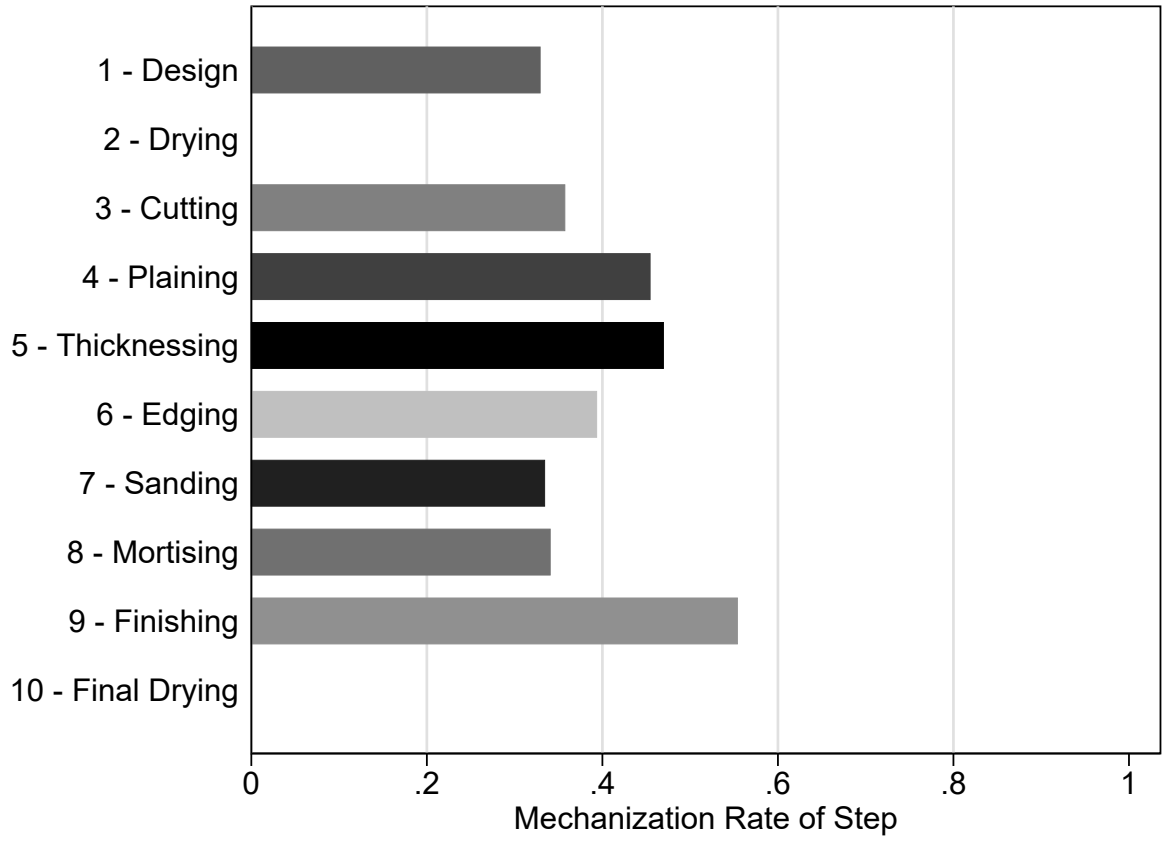
The Market for Machines: Indivisibilities



- Machines have high capacity + Firms are small = Each firm only needs 1

Back

Variation in Mechanization

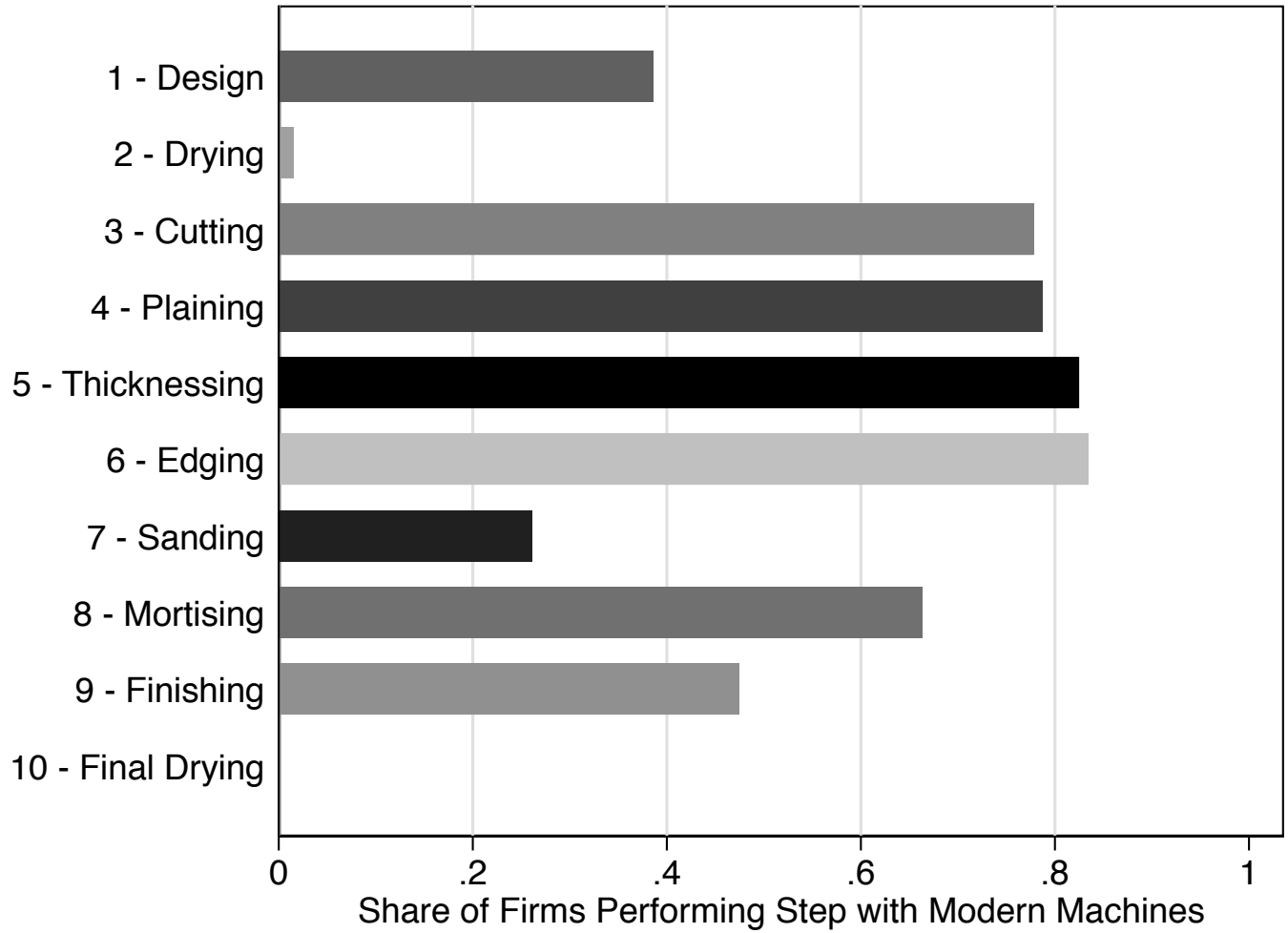


- Mechanization rate = 1 if uses as many machine types as mkt leader

Extensive

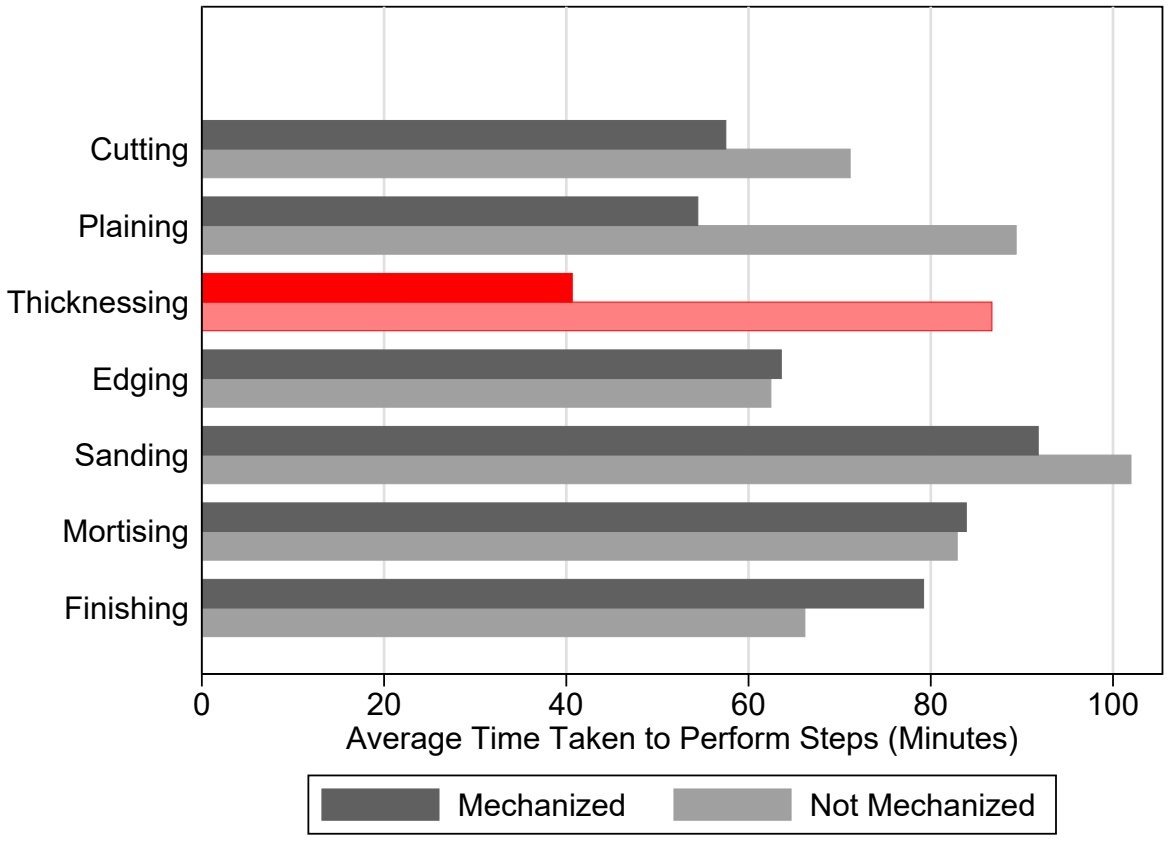
Back

Mechanization of Production Steps: Variation



Back

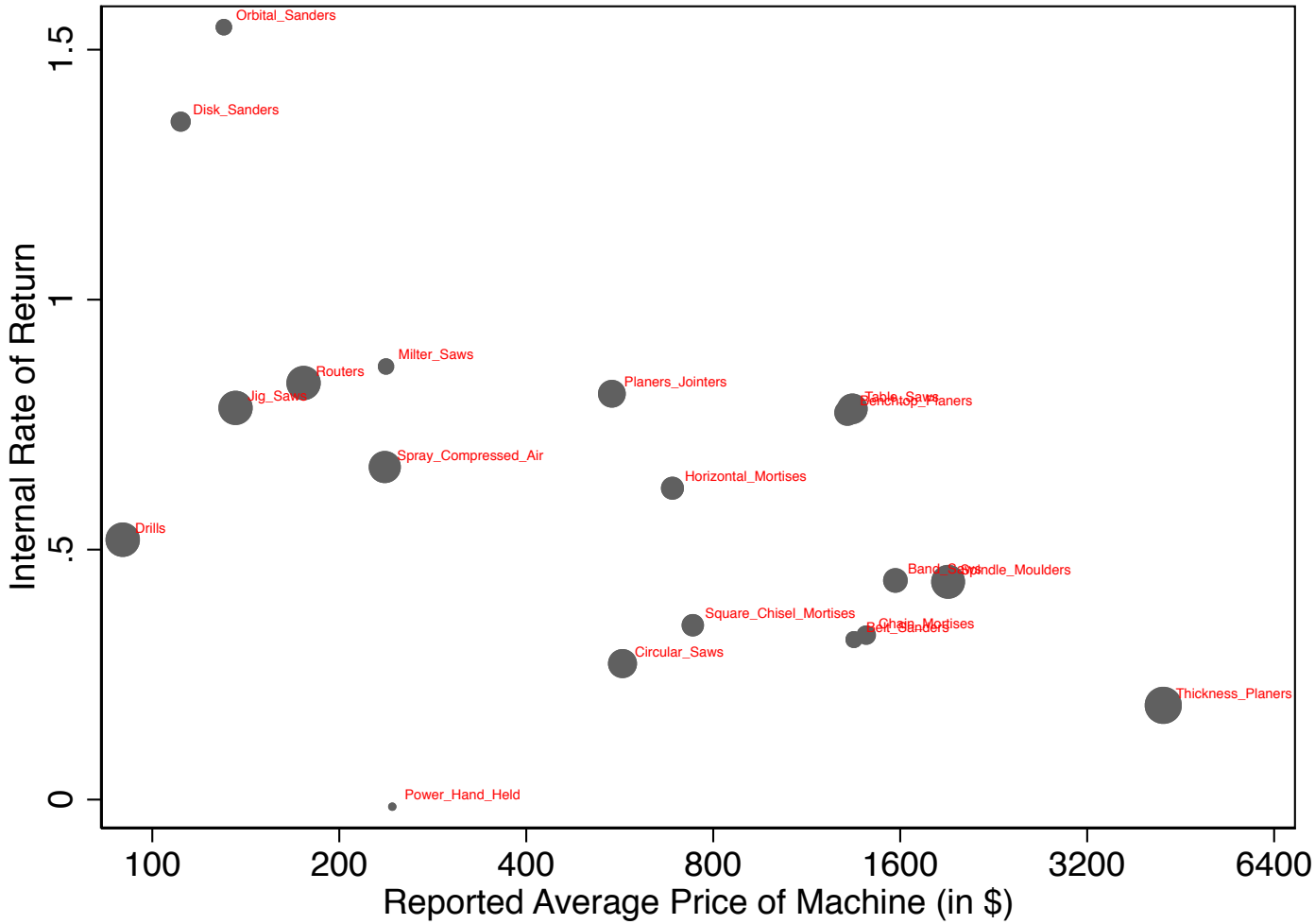
Productivity Gains from Mechanization



- Substantial time savings from mechanization
- Mechanization main correlate of productivity

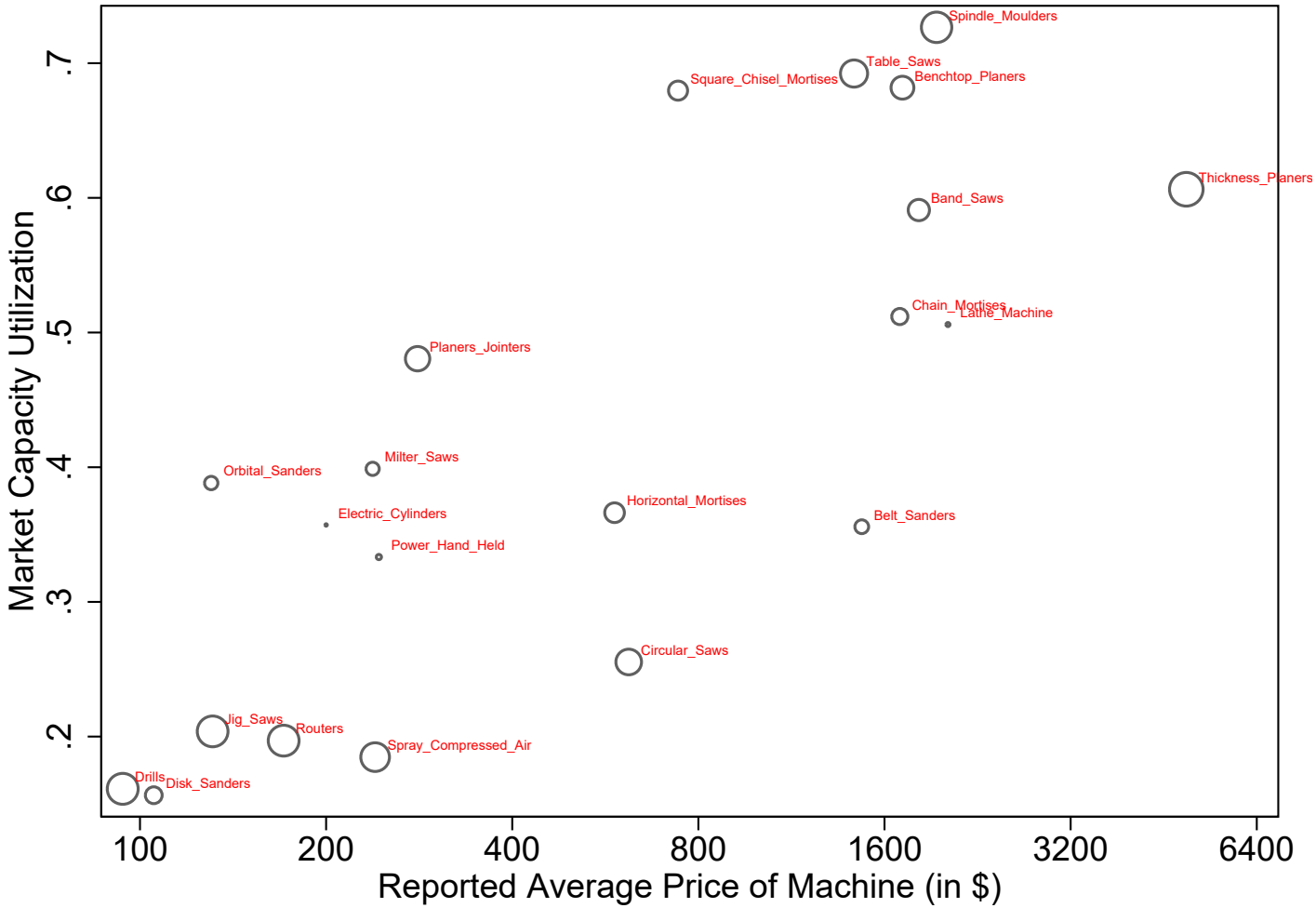
Back

High Capacity Machines Have Lower Rental Price



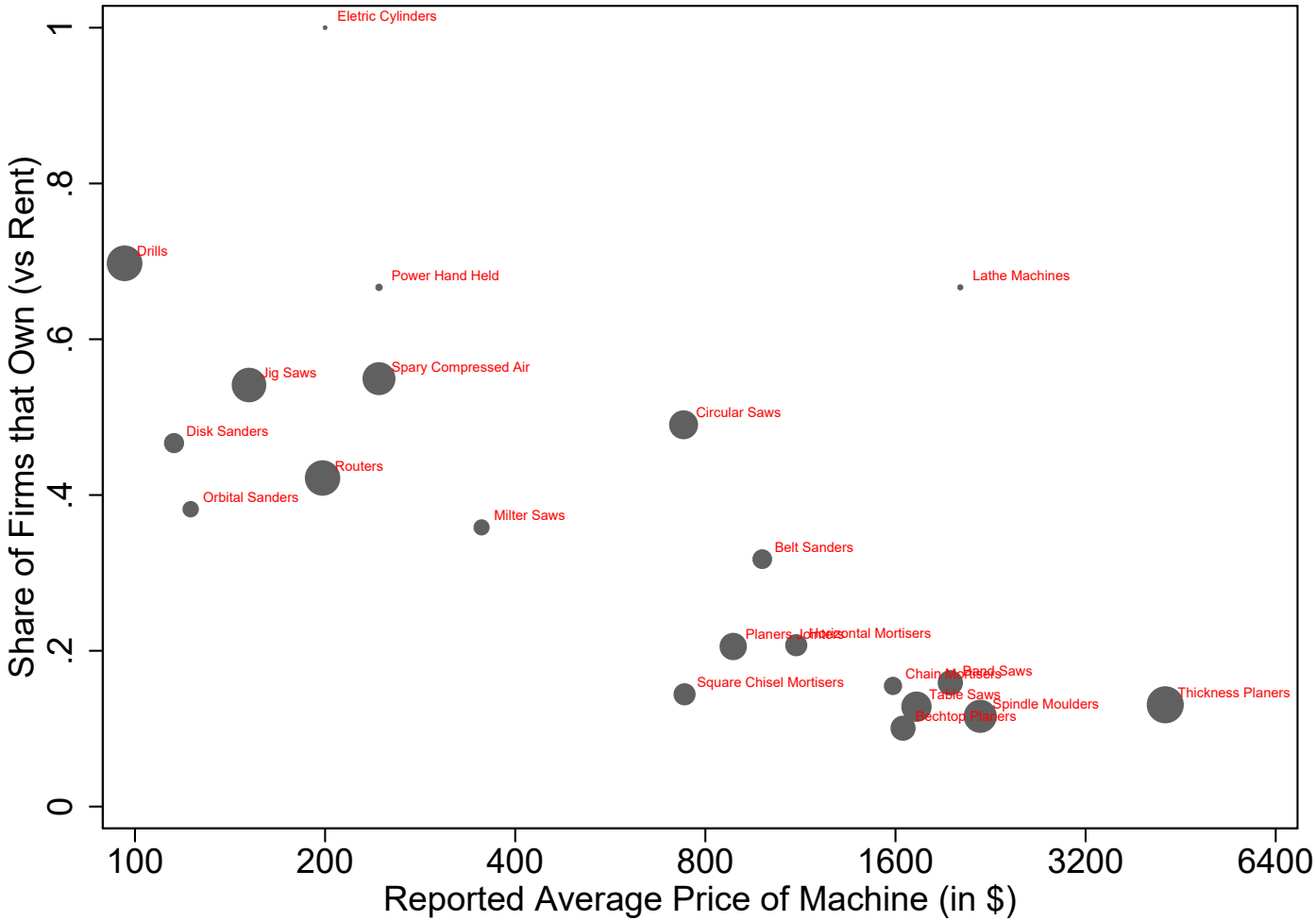
Back

Expensive Machines are Used More Intensively



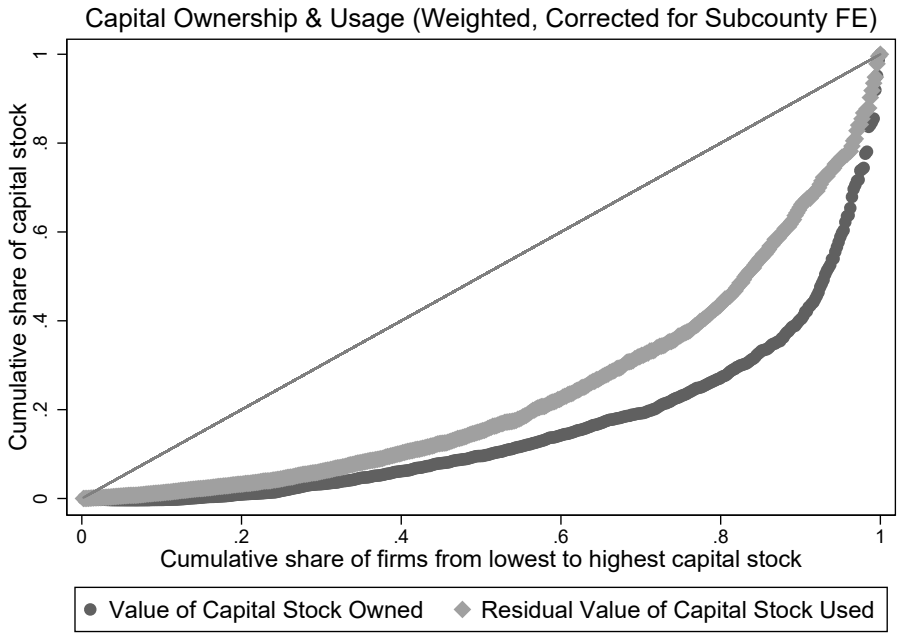
Back

Rentals are Most Common for Expensive Machines

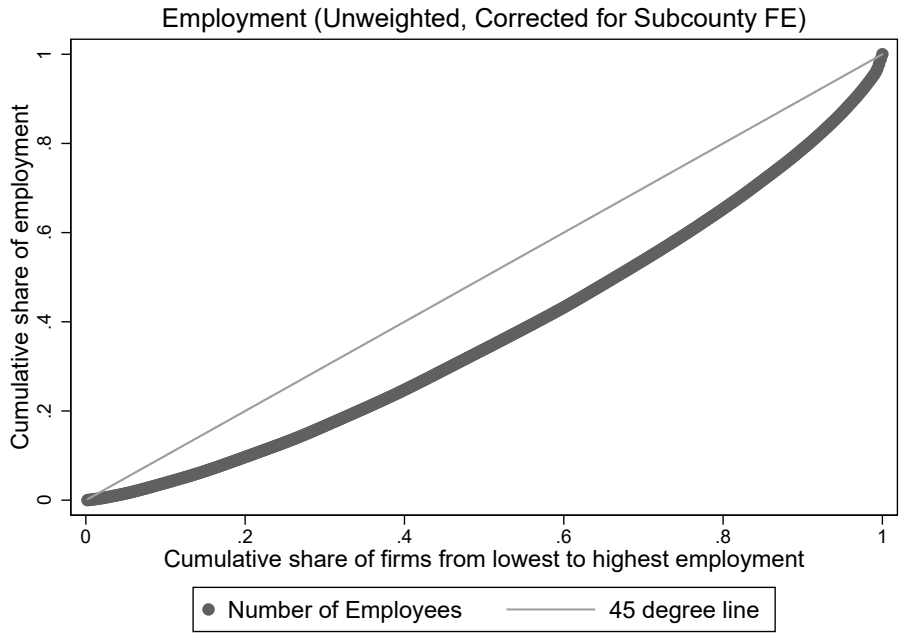


Back

Concentration in Machine Ownership



(g) Machines



(h) Employment

Back

Scale Economies Driven by Labor?

- Labor input as another driver of scale economies?

- Key facts about usage of the labor input:
  1. worker characteristics not significant predictors of profitability
  2. weak link between size and labor organization within the firm
  3. cost of labor rises with firm size
  4. labor market frictions are an important constraint

  [Bassi and Nansamba 2019, Hardy and McCasland 2017]

SkillsPW
Org
SizeWages
Frictions

⇒ If anything, *diseconomies of scale* in labor input

Back

Determinants of Demand

- Key features of the output market where firms operate:
  1. demand is highly local: most sales within parish [Jensen Miller '18] Local
  2. lack of demand cited as important constraint Demand
  3. dispersion in revenues driven by quantity rather than price Disp
  4. little competition on prices across firms Comp

$\Rightarrow$ Suggests imperfect competition in output market

Back

Equilibrium in the Rental Market

- For each machine x, demand and supply of capacity must be equal
- Given the properties of Frechet, supply S_x and demand D_x are

$$S_x \equiv \int\int \left(C_x^* - k_{o,x}^*(q,r)\right) \varphi_{o,x}(q,r)\, dG(q,r)$$

$$D_x \equiv \int\int k_{r,x}^*(q,r)\, \varphi_{r,x}(q,r)\, dG(q,r)$$

where C_x^* and $k_{o,x}^*(q,r)$ are equilibrium capacity, and capital for owners and renters; further, for each $m \in \{r,o\}$, then

$$\varphi_{m,x}(q,r) = \frac{c_{m,x}\left(y^*(q,r);r\right)^{-\theta}}{\sum_{k\in\{I,r,o\}} c_{k,x}\left(y^*(q,r);r\right)^{-\theta}}$$

Back

Rental Market Wedge τ_x: Results

Dependent variable: Log Monthly Machine Hours

	(1) Step 3	(2) Step 4	(3) Step 5	(4) Step 6	(5) Step 7	(6) Step 8	(7) Step 9	(8) Pooled	(9) Pooled	(10) Pooled Firm FE
Machine is Rented (Yes = 1)	-0.635***	-0.880***	-0.587*	-0.709***	-0.724**	-0.491**	0.203	-0.558***	-0.757***	-0.333***
	(0.171)	(0.219)	(0.315)	(0.166)	(0.295)	(0.195)	(0.230)	(0.110)	(0.114)	(0.083)
Observations	472	309	251	485	125	361	183	1,728	1,728	1,728
Adjusted R^2	0.260	0.430	0.345	0.324	0.440	0.336	0.287	0.347	0.263	0.728
Machine FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	No	No	No	No	No	No	No	No	No	Yes
Subcounty FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Log Wage Bill Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Machine Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Weighted	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No

Back