Supply Chain Design and Adoption of Indivisible Technology

Liang Lu[1], Thomas Reardon[2], and David Zilberman[1]

1. UC Berkeley
2. Michigan State University

Prepared for SCC-76 2016 Annual Meeting

Mar 18 2016

Berkeley
UNIVERSITY OF CALIFORNIA

Outline

1 Motivation

2 Background

3 Indivisible Technology Adoption Model

4. Discussion

Motivation

- This paper is under a unified theme:

  Innovation and Supply Chain Design

- Key notion: Entrepreneurs who develop an innovation design supply chain to gain

- From raw product to processed product—value added beyond the farm gate.

- Such as processed chicken, beer (essentially processed barley), biofuel (processed corn, sugarcane, etc.)

The pipeline

1. Should you find partners to produce your feedstock? (Du et al., 2016, AJAE R&R)

1. Welfare implications of the innovator (aka middleman)'s supply chain design (Lu, Reardon, and Zilberman, 2016 Food Policy special issue)

1. Dynamic considerations of market structure under patent/imitation (Lu, Shen, and Zilberman, ongoing)

2. This paper: Supply chain design and adoption of indivisible technology (AJAE R&R)

Background

(Reardon 2015) In the 2000s in Indonesia, due to

- Increased demand for fruit
- Urbanization and inter-island trade

, there was a sharp change in technology and cultivar of mangoes:

- Use of hormones to extend the season
- Use of pesticide for quality
- Use of pruning for productivity
- Shift to high quality varieties

Background: Sprayer-Traders

- Farmers face constraints of human, physical, and financial capital and labor to apply these technologies
- Risk of in-sourcing, plus capital constraints, led farmers to demand outsourced service
- This demand induced the rise of "sprayer-traders" who supply services cum physical and human capital to the farmers to implement the technology change plus logistics and marketing services

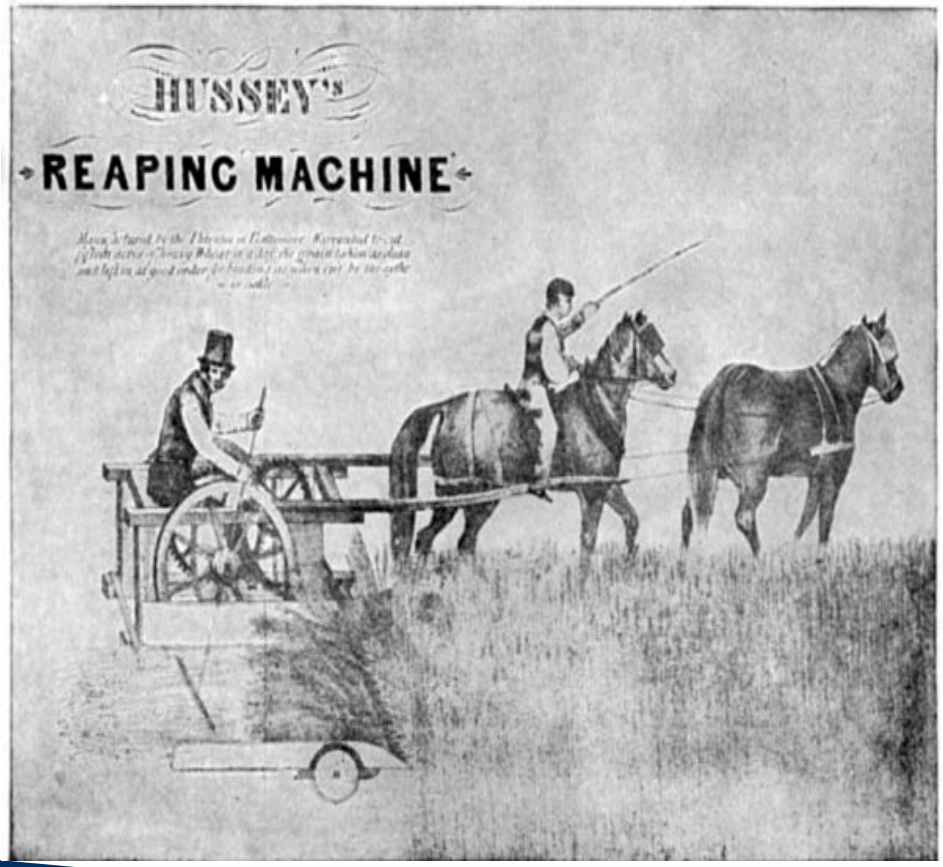
Background

- “Sprayer traders” add a rental service node to the supply chain

Its emergence is analogous to mobile harvesting machine teams

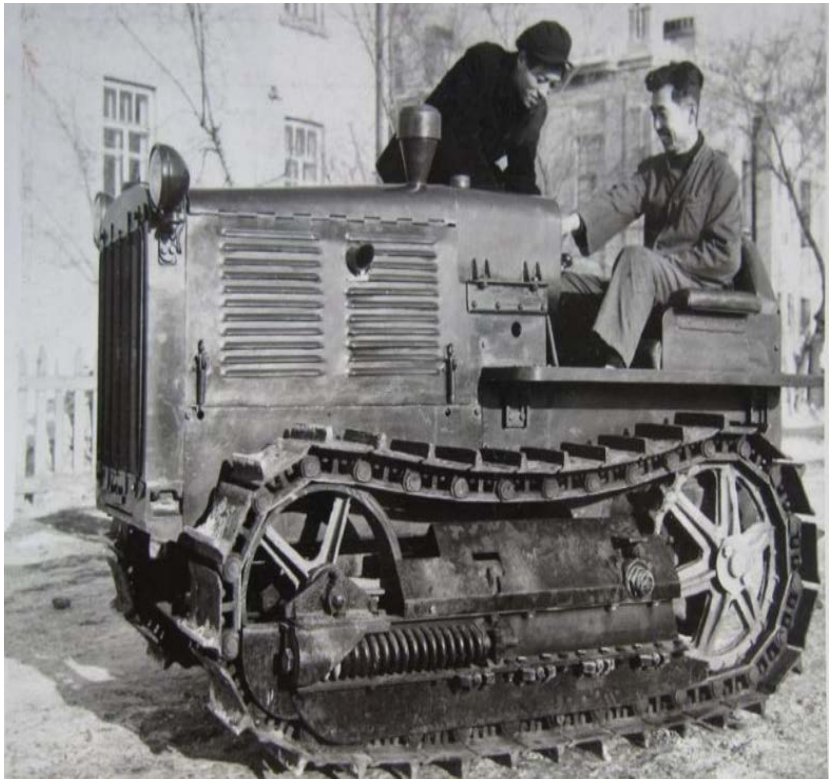
- US in 1800s/1900s
- Argentina in 1990s
- China in 2000s

Adoption of Indivisible Technology



- Olmstead's many papers:
- Models of technology adoption didn't consider the possibility of sharing or renting
- Gave examples on mobile harvest teams

Machinery Adoption in China



- Zhang et al.(2013):
- Failed adoption in 50s, 70s
- Rental services emerge in early 2000s
- Increased labor cost is a driving factor

Adoption and rental of new equipment

- Mechanical innovations have a minimal scale greater than scale of most farms
  - Some entrepreneurs buy equipment and sell custom services
  - Other buy customs services
  - Some do not use technology at all

- Rental services allows the possibility of separation between technology adoption decisions and machinery ownership decisions

- Questions
  - Who belong to which group
  - How prices and demand affect outcome

Indivisible Technology Adoption Model

Berkeley
UNIVERSITY OF CALIFORNIA

Goal of the modeling

- Define the joint “Machine renter-machine buyer-machine provider” equilibrium

- And comparative statics results

- Need to characterize three markets:
  1. Output market
  2. Rental service market
  3. Machine purchase market

Model Setup

- The farm side:
- Each farmer is endowed with a vector of attributes and farm characteristics $\mathbf{x} = (x_1, x_2, \ldots, x_n, L)$.
- x_i: attribute or farm characteristics and L stands for farm size.
- The joint density function of these attributes and characteristics is denoted by f(x).
- $h_i(\mathbf{x}; s)$: farmer's yield per acre as a function of the attributes **x**, adoption choice i and some productivity shock s.
- i is the machinery adoption indicator, and j is the machinery rent or buy indicator (j = 0 indicates renting).

Model Setup

- The demand of the agricultural output is D(p) where p is the output price.

- The the supply function for the machine is S(I, r, M), where I is the cost of machine, the capacity of the machine is M acres of land, the per acre cost of the machine is denoted by r.

Model Setup (Cont.)

- We use π^d to denote a farmer's profit under decision d
- d = 0, 1, 2 which indicates non-adoption, renting, and buying respectively.
- The set of adopters A is all the farmers such that using the machinery, either through renting-in or buying, achieves higher profit than not using it:

$$A = \left\{ x \in X \mid \pi^1 > \pi^0 \; or \; \pi^2 \geq \pi^0 \right\}.$$

- Then the set of non-adopters is the complement of A: X/A or A^c.
- Set of Renters

$$R : R = \left\{ x \in X \mid \pi^1 \geq \max\left\{ \pi^2, \pi^0 \right\} \right\}$$

- and the set of buyer

$$B : B = \left\{ x \in X \mid \pi^2 \geq \max\left\{ \pi^1, \pi^0 \right\} \right\}.$$

Aggregate Demand and Supply

- The total final output, denoted by Q_O^s is all the production under yield function h_1 for adopters and h_0 for non-adopters.

$$Q_O^s(p,r,I,M,s) = \int_{x\in A} h_1(x) f(x) L\, dx + \int_{x\in A^c} h_0(x) f(x) L\, dx.$$

- The aggregate demand for machine rental services, denoted by is the integral over the acreages of the renters' set:

$$Q_R^d(p,r,I,M,s) = \int_{x\in R} f(x) L\, dx.$$

- The aggregate supply of rental services is the sum of services from both buyers and service providers:

$$Q_R^s(p,r,I,M,s) = \int_{x\in B} f(x)(M-L)\, dx + T(r,I,M).$$

- Machine demanded are either from buyers or service providers:

$$Q_M^d(p,r,I,M,s) = \frac{1}{M}\left[\int_{x\in B} f(x) L\, dx + T(r,I,M)\right].$$

Defining the Equilibrium Concept

- Definition

The joint supply chain market clearing condition is determined by the following set of conditions:

1. Clearing of the output market:

$$Q_O^s\left(p^*, r^*, I^*, M, s\right) = D\left(p^*\right).$$

2. Clearing of the rental service market:

$$Q_R^d\left(p^*, r^*, I^*, M, s\right) = Q_R^s\left(p^*, r^*, I^*, M, s\right).$$

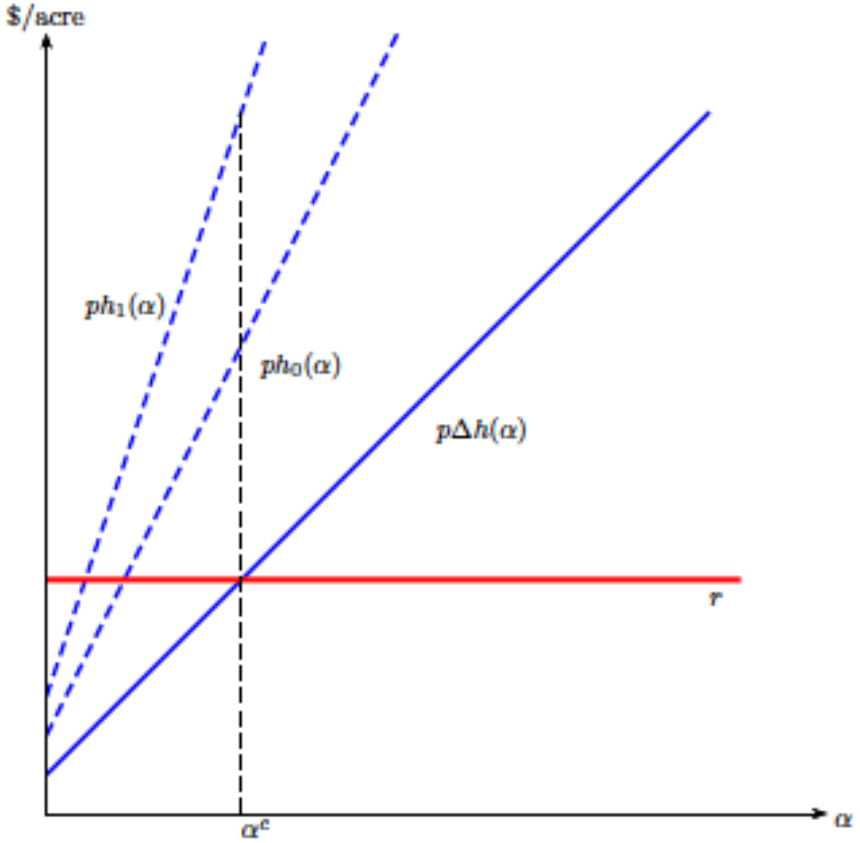
3. Clearing of the machine purchase market:

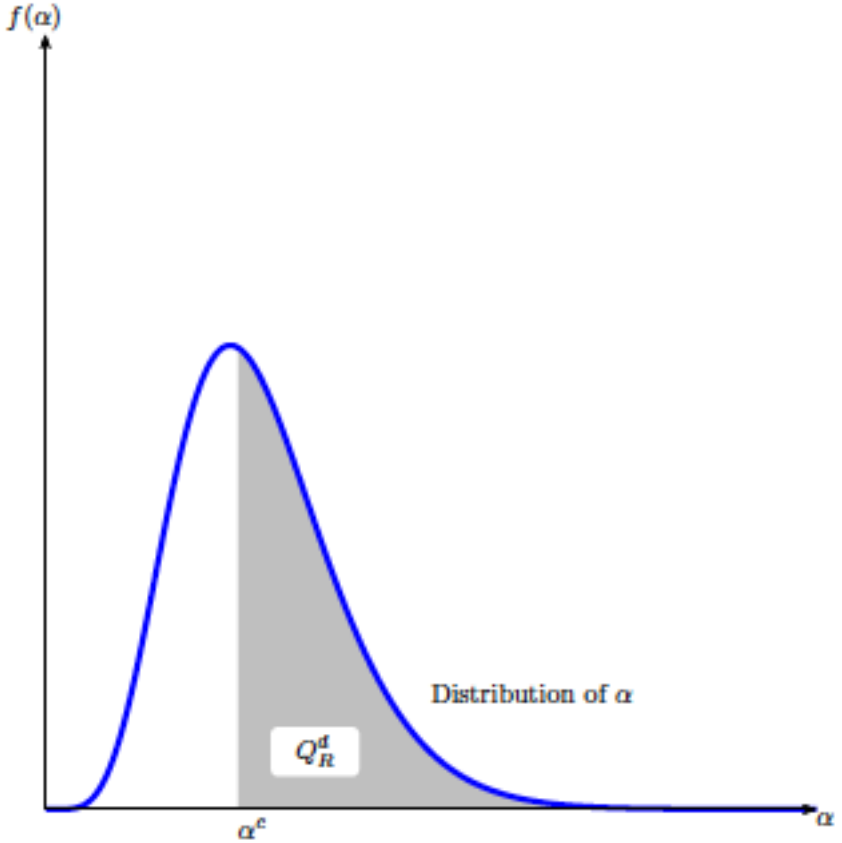
$$Q_M^d\left(p^*, r^*, I^*, M, s\right) = S\left(I^*, r^*, M\right).$$

4. Linkage between the machine purchase and rental service market:

$$r^* = \frac{I^*}{M}.$$

Figure 1. Adoption threshold and aggregate demand for machine rental





Main Results for Case 1.

Case 1. Yield is not affected by scale and land quality is heterogeneous

- Result 1.

  As the demand of the agricultural product increases,

  – Market equilibrium rent and number of machine supplied increases.
  – The threshold land quality for machine adoption decreases,
  – The change in output price is higher than the increment in rent.

- Result 2.

  As the capacity of machinery increases (one machine could be used on more acres), market equilibrium rent goes down and there is more machine adoption in equilibrium.

Main Results for Case 2.

Case 2. Heterogeneous land quality and farm size when size affects productivity (Foster and Rosenzweig, 2000)

- Result 5

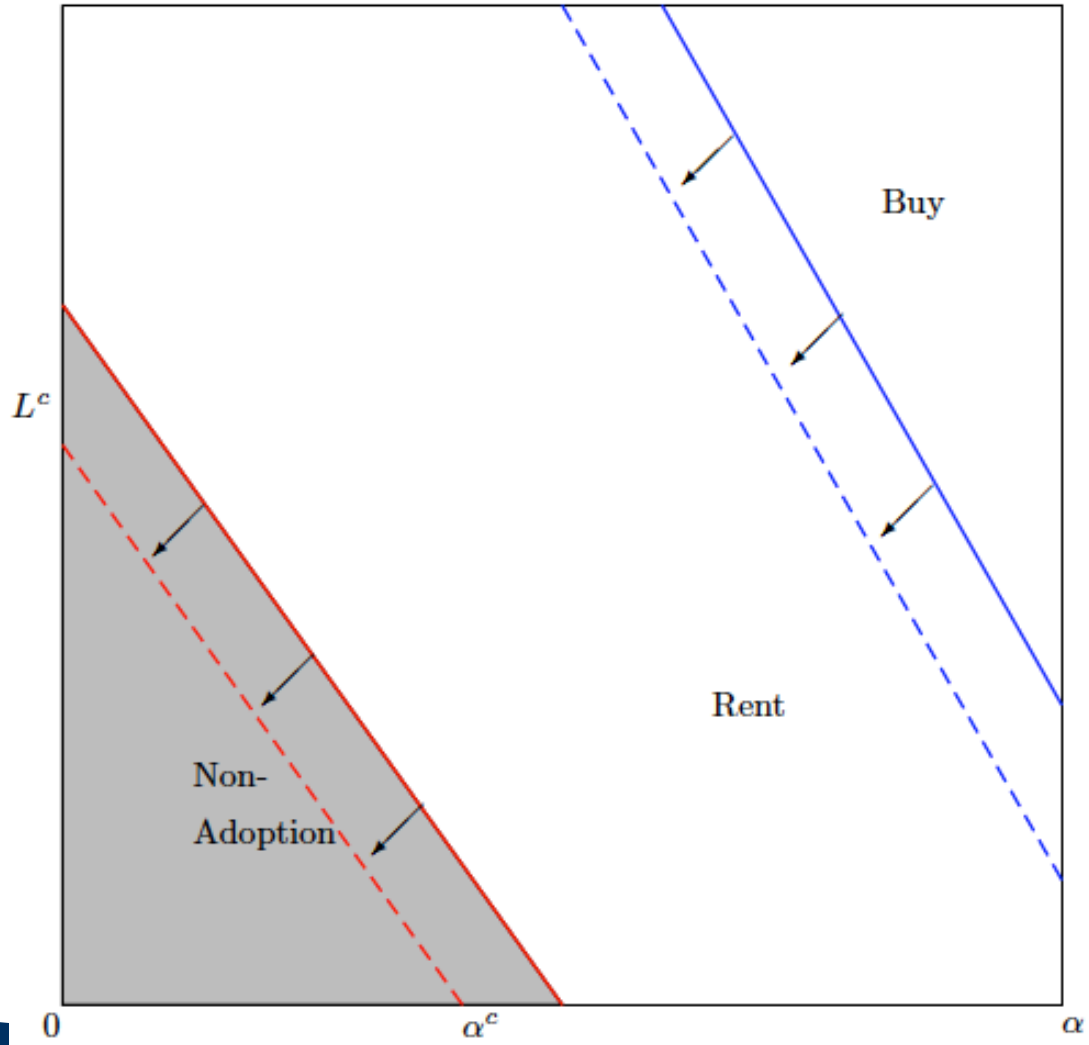
  As demand for output increases,

  – both the set of adopters and the number of farms buying the machine increases.
  – However, the effect on equilibrium rent is uncertain.

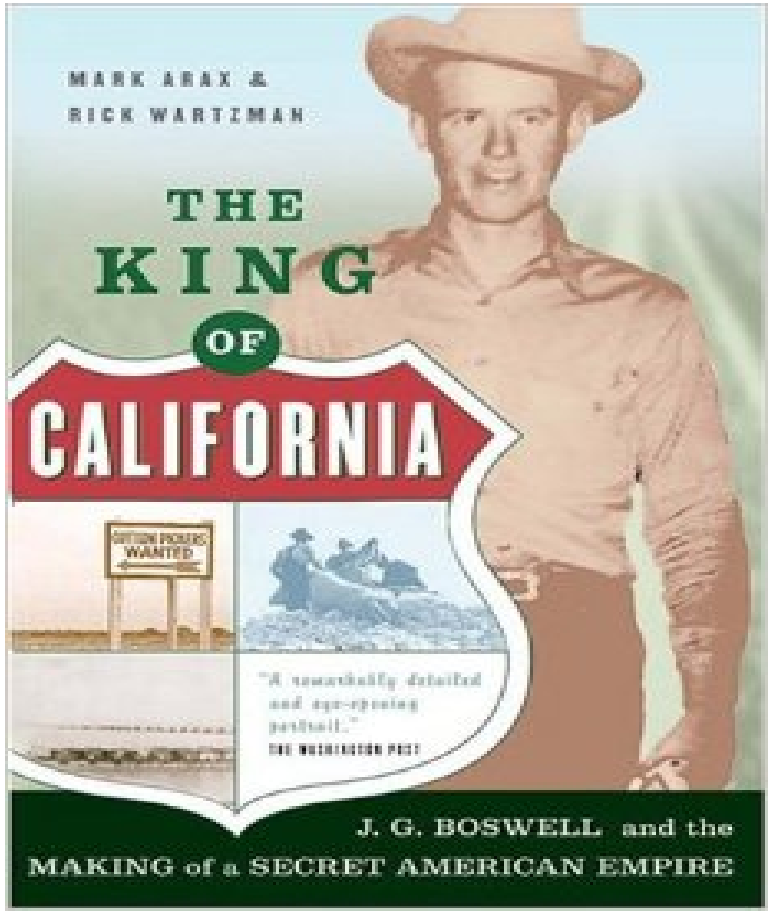
  As the cost of the machine decreases,

  – the set of adopters does not change
  – some large farms switch from renting to buying.
  – Both equilibrium rental services and the rent go down.

Figure 2. Adoption and Ownership patterns



The Case of J.G. Boswell



- Negative correlation between critical land quality and farm size
- larger farms are more likely to adopt technologies that allow economic viability in locations with adverse condition.
- Boswell's cotton farm case

Berkeley
UNIVERSITY OF CALIFORNIA

Discussion

- A few things we did not explicitly model:

    1. Variable input use.
    2. Risk considerations.
    3. Market power.

Discussion

- Variable input: an important issue when there is:
  - Minimum wage policies or significant labor force change
  - Self-checkout machines or self-ordering machine.
  - Farmers migrating from farming to other jobs.
- Market power: even harder to predict market outcomes
  - Single machine seller
  - Singer rental service provider
  - Or both

Rental Service as a risk management tool

- Adoption of novel technology increases operation risk.
- If we go back to the RBH theory, increased business risk needs to be compensated by lower financial risk.
- Rental service may be preferred to buying if expected gain is not too high.
- In this sense, rental service provides a risk management tool.
- Rental service may include a risk premium component.