TECHNOLOGY ADOPTION

I. Some Basics

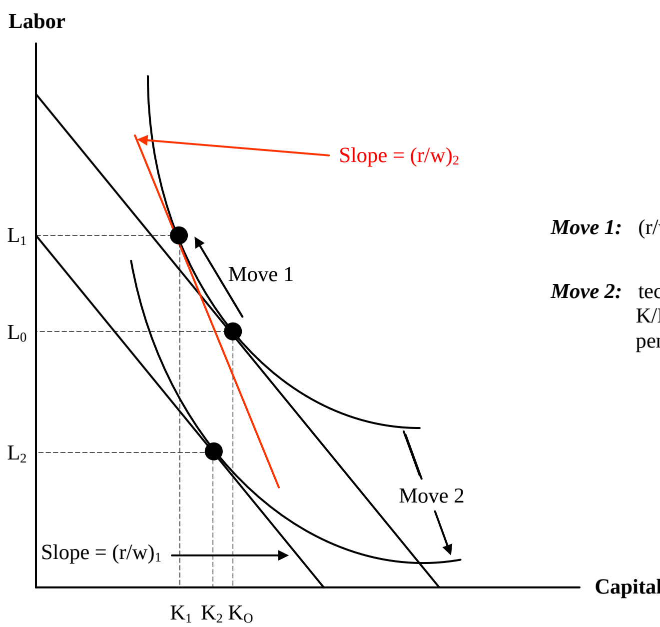
A. Scale Neutrality vs. Scale Biased

- Innovation is scale neutral if it (and its complements) is divisible across an entire range of outputs

- **Scale neutral innovations:** Seeds, fert, water from existing well

- **Scale-biased innovations:** Tractors, combines, wells

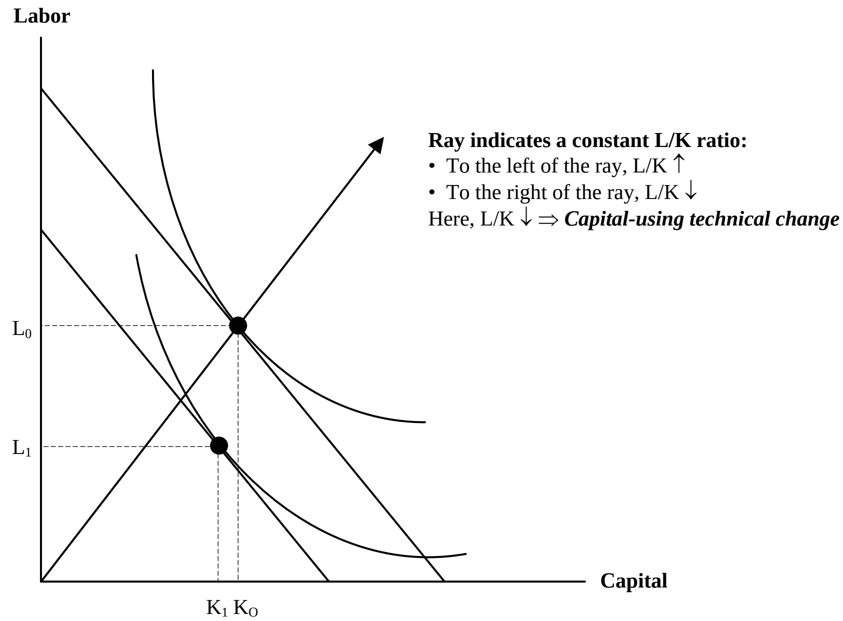
B. Factor Substitution vs. Technological Change



Move 1: (r/w)↑ ⇒ (K/L)↓

Move 2: tech chg. ⇒ K ↓ and L ↓, K/L may rise or fall depending on *factor bias*

C. Biased Technical Change



- If $\mathbf{L_1/K_1 < L_0/K_0}$, then technical change is **L-saving ⇔ K-using**

⇒ income share of labor falls

- If $\mathbf{L_1/K_1 > L_0/K_0}$, then technical change is **L-using ⇔ K-saving**

⇒ income share of labor rises

- **It is useful here to think of "K" as LAND:** Does the new technology benefit owners of land or owners of labor (workers)?

Stylized facts from LDC Agriculture

- Land-saving technologies include seeds, fertilizer
- Labor saving technologies include tractors, combines
- Not all mechanization is labor saving (e.g., if it promotes double cropping)

D. <u>Adoption vs. Diffusion</u>

Adoption = Decision by **individual** farmer to employ a new technology

Diffusion = Spread of new technology use within a given geographical area or population

II. MICROECONOMICS OF TECHNOLOGY ADOPTION

Huge empirical literature on the subject (**<u>Feder, et al is nice review</u>**)

A. <u>Farm Size</u>

<u>Indivisible inputs</u> Small farms can limit the adoptability (absent a rental market) due to high **fixed costs.** (Example: tractor, tubewell, oxen)

<u>Divisible inputs</u>

(a) Small farms tend to adopt more slowly than large farms, again due to **fixed costs of learning**.

(b) But small farms **catch up.**

(c) For some inputs (e.g., fert, pesticides) the **intensity of use by small farms exceeds that of large farms.**

Reasons: i. Greater subsistence orientation;
ii. More efficient irrigation;
iii. More (high quality) family labor.
iv. Better quality land ⇒ Marginal product of inputs high

****CAVEAT: Farm size proxies for lots of other stuff, like risk aversion, credit constraints, wealth, access to information.**

B. <u>Risk slows adoption</u>

- Hard to measure empirically (hence often ignored)
- Popular notion: farmers who are risk averse will <u>wait longer</u> to adopt
- Melinda, Paul & Howard (also, Roumasset): Evidence that both risk aversion and safety-first criteria are important explanations of maize adoption in Malawi.
- Risk can underlie **partial adoption** (due to portfolio considerations)
- **Information acquisition and risk are hard to disentangle empirically**

C. <u>Human Capital speeds adoption</u>

- Schultz: new technology represents a disequilibrium impulse which causes inefficient resource allocation until **learning** and **experimentation** lead to a new equilibrium.
- Human capital ⇔ ability to learn faster (i.e., quicker path to new equilibrium)
- Empirical support that **education (= human capital?)** is related to **early adoption** and to **greater productivity** (of improved varieties only)

D. <u>Labor Availability</u>

- Depends on whether the technology is labor-using (like HYV's) or labor-saving (like ox cultivation)

- **Also depends on what the bottlenecks are; for example:**
  - W. Africa peak season labor scarcity facilitates ox and tractor adoption
  - Nonadoption of labor intensive tech where family labor is scarce (e.g., parts of India)
  - Adoption of labor intensive HYV rice in labor abundant Taiwan

E. <u>Credit</u>

- **Capital** is required to **finance adoption** of many types of new technologies (e.g., tractors, oxen, hybrids, fertilizers)

  ⇒ **Differential access** to credit leads to differential adoption

- Empirical evidence supports credit constraints hypothesis, even for divisible inputs with low fixed costs
  - **Complementary lumpy inputs** may be part of the story here.

- Credit subsidy programs don't seem to help (often because they're coopted by agents for whom credit constraints aren't binding – e.g., large landowners)

F. <u>Land Tenure slows *rate* of adoption</u>

- More likely to affect rate of adoption than adoption per se
- **New technology may presage changing tenure arrangements**
- *Baiduri:* Landlord might block adoption of new technology because it reduces credit (interest) income more than raising crop income.
- *Newbury:* If contracts are interlinked, then LL will alter interest rate
- Credit constraints affect pure tenants more than landowners who are also tenants
- Have to be clear about who is making input use decisions (tenant or owner)

G. <u>Supply Constraints</u>

- Significant **complementarities** among inputs (e.g, seed-fert-H_2O)
- Supply disruption for one input may limit adoption of another
- Key role of gov't marketing **infrastructure**/input delivery system

H. <u>Suitability of Specific Technologies</u>

- Farms differ widely in terms of soil quality, H_2O availability, proximity to manure collection center, etc.
- The better the production environment, the greater the probability of adoption

I. <u>Stepwise Adoption (Byerlee & Hesse de Polanco)</u>

- Many innovations promoted as a "package" of technologies
- Much evidence points to stepwise adoption
- Adoption in order of profitability and risklessness
- Risk aversion, learning important explanators of adoption order
- **Key result**: Profitability, not yield increase, underlay the order of adoption (i.e., HYV-herbicide-fertilizer, **<u>NOT</u>** HYV-fertilizer-herbicide

TECHNOLOGY DIFFUSION

- Theoretical and empirical evidence on adoption indicate widespread differences across farms in:
  a. Whether or not they adopt
  b. How rapidly they adopt
  c. Whether they adopt fully or partially

- In the aggregate, this gives rise to **S-shaped diffusion curves**

- S-curve is summarized by three parameters
  a. Date of initial adoption **(origin)**
  b. Relative speed of adoption **(slope)**
  c. Final level of aggregate adoption **(ceiling)**

A. <u>Origin</u>

- **Hybrid corn study:** Initial adoption of hybrid corn depends on availability of seed which in turn depends on expected profit of the seed company exceeding the cost of development:

Eπ = f(mkt size, dev't cost) → availability → initial adoption

Hybrid corn story is relevant for an existing innovative approach. But what causes research that produces a successful innovation?

a. Luck

b. **Induced innovation hypothesis:** Both public and private entities respond to relative prices/factor scarcities ⇒ scientific effort devoted to developing methods/technologies that use more of abundant resources and less of scarce resources.

<u>Examples</u>

1. Labor abundant/land scarce ⇒ yield enhancement

2. Labor scarce/land abundant ⇒ mechanization (labor saving)

B. <u>Variables determining the Rate of Diffusion</u>

1. **Yield differences** between new and old varieties
   - i.e., **shifts in unit cost of prod** (these vary across farms)
   - **Seeds, fert:** adaptability to different prod environments
   - **Lumpy inputs:** May be scale biased until rental mkts develop

2. **Impact on yield variability:** risk enters here

3. **Distribution of human capital and information**

4. **Stepwise adoption** (i.e., time between steps)

C. Ceiling

Cumulative adoption of less than 100% may be due to:

1. **No yield or cost advantage** for some farmers
2. **Food preferences:** some farmers prefer traditional variety in diet
3. **Yield variability** (risk considerations)
4. **Safety first** reasons (again, risk)
5. **Differential success of adaptive research**

GREEN REVOLUTION

A. Origins

Ford Foundation → IRRI (1960)

Rockefeller Foundation → CIMMYT (1966)

Work on semi-dwarfs began in the 1940s

Rice: **DGWG** (China) → IR8

Wheat: **Norin** (Japan) x Brevor (WA) → Range of semidwarfs

About Semi-dwarfs

- Higher proportion of biomass devoted to grain
- **Short stature** → No lodging problem
- **Fertilizer responsive**
- Photo insensitive & shorter duration → **higher cropping intensity**
- Best suited to well-watered (e.g. irrigated) conditions
- **Self-pollinating** → self-propagating (no reliance on seed distrib. infrastructure after initial introduction)

B. <u>Diffusion</u>

- Wheat first introduced in Mexico, India, Pakistan
- Rice first introduced in Philippines, India
- Basic source of germplasm from IARCs with **adaptive breeding** in by NARS.
- Continuing developments in breeding led to greater emphasis on:
  - Disease resistance
  - Yield stability
  - Drought tolerance
  - Timing (e.g., late planting)

C. <u>Ruttan's Generalizations about Rice and Wheat HYVs</u>

1. Rapid adoption where technically and economically superior

- 60 – 90% adoption in first four years was common

2. Farm Size, Tenure not Serious constraints on adoption

- Large farms were early adopters but small farms caught up

3. Scale neutrality and factor neutrality of HYVs

- No differential productivity effects (large vs. small, own vs. tenant)

4. Increased demand for labor

- Required more labor per unit of land (**land-saving**)
- Had **higher cropping intensity**
- Required **large increases in labor use on harvesting, threshing**
- Led to significant **migration into adopting areas**

DIGRESSION: FARMSIZE–PRODUCTIVITY RELATIONSHIP

Ideal productivity measure: $\frac{\text{Profit}}{\text{Assets}}$ **= π/unit of economic size**

- Few empirical studies have come close to measuring this
- Those that have indicate a significant negative relationship **between farmsize and profit** for all but smallest farmsize classes
- Lots of empirical work shows this inverse relationship using π/acre or output/acre.

<u>Basic Analytical Issue</u>

Large farm "assets"	vs.	Small farm "assets"
Scale economies (lumpy assets)		Rental mkts dissipating IRS
Accsess to credit		Family L quality advantage
Superior (?) management skills		Supervision economies

MECHANIZATION

Types

- **Land Prep:** Tractors, cultivators, tillers
- **Planting:** Tractor plows, seed drills, disk harrows
- **Harvesting:** Combines, harvesters
- **Post-harvest:** Threshers

Purported Positives

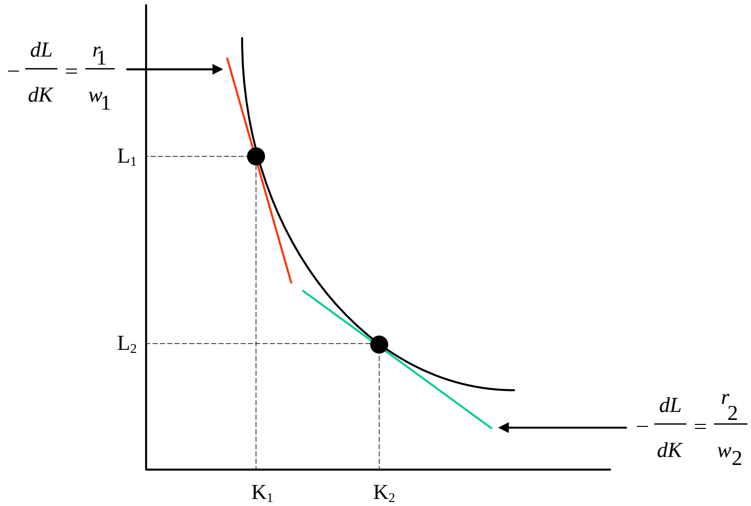
1. **Timeliness** of planting ⇒ increased yields
2. **Timeliness** of planting ⇒ increased cropping intensity
3. Planting improvements ⇒ **facilitate weeding** ⇒ increased yields
4. Seed drills, other planting techs ⇒ better H_2O use ⇒ yield ↑, σ^2 ↓
5. Tractors ⇒ **area expansion** unfeasible with bullock, human labor

Purported Negatives

1. Displacement of labor, tenants
2. Negative income distributional effects due to differential adoption

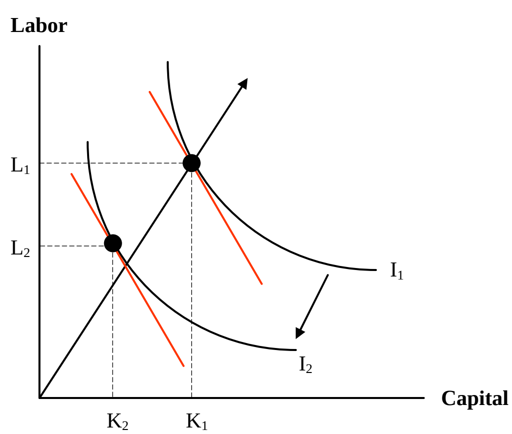
TWO VIEWS OF MECHANIZATION (BINSWANGER)

I. <u>"Substitution" View</u>



- Mechanical and human power are perfect subsitities
- Factor price relationships drive switch to mechanical technologies
- Relative price of labor might rise due to labor scarity **or** distortions that lower the relative price of machines

II. <u>Net Contributor View</u>



Relative factor prices are constant, but new mechanical technologies lead to move from isoquant I_1 to $I_2 \Rightarrow$ **Labor-biased technical change**

III. Implications

1. Net contributor view sees mechanization as an **engine of growth** due to better tillage, more timely operations, yield increases, double-cropping (i.e., more output from less inputs)

2. Substitution view sees mechanization as moving along an isoquant

⇒ Alter factor proportions to achieve **allocative efficiency**

3. Both can happen at once, of course.

IV. Binswanger's South Asia Tractor Survey

- Some tractor farm studies indicate higher yields, but these are due to fertilizer.
- **No evidence supporting the timeliness arguments**
- Utilization related to farm size

Basic findings:

1. Tractorization due to substitution
2. Constant real wages, falling tractor prices (due to subsidy in Pak.)
3. **India:** Tractorization mainly confined to areas where real wages ↑
4. Large farms tractorized to avoid labor mgmt problems in India

WHY TIMELINESS DOESN'T HAPPEN WITH TRACTORS:

1. **Economics of Capacity Utilization (fixed cost explanation)**

- Use tractor 10 days out of 365
- 20hp may not be enough to insure timeliness, whereas 35hp might
- But 35hp costs alot more
- Substitution possibilities exist – bullocks, human labor

***Punchline*:** **Low cost of tractor requires relatively high level of utilization, but this spreads the tractor more thinly over a specific plot of land (Binswanger)**

2. **Alternatives exist for breaking bottlenecks other than tractors**

- Example: Stationary thresher frees up bullock labor.

3. **Short duration varieties substitute for tractors.**

4. JAYASURIY, TE, AND HERDT EXPLANATION:

Let P = price of tractor, r = per hr. rental rate, i = interest rate, c = per hr. cost (op. & maintenance):

$$NPV_0 = \left[\sum_{t=1}^{T} \left(\frac{1}{1+i} \right)^t \cdot (r-c) H \right] - P$$

At break even, NPV = 0:

$$\Rightarrow H^{BE} = \frac{P \cdot \sum (1+i)^t}{r-c} \quad \Rightarrow \quad \frac{\partial H^{BE}}{\partial P}, \frac{\partial H^{BE}}{\partial i}, \frac{\partial H^{BE}}{\partial c} \; > \; 0 \; > \; \frac{\partial H^{BE}}{\partial r}$$

<u>**Implications**</u>

1. Subsidized credit, tractor prices, fuel lead to greater tractor utilization
2. Usage increases with rental rate; however, if there's a labor surplus then this retards the growth of "r" and limits the likelikhood of tractorization enhancing productivity
3. Implementation of their model with Philippine data indicate that existing prices and costs mean that small cultivators are not profitable in most cases.

B. Jayasuriya & Shand: Rice Cultivation Mechanical Tech.'s

- Initial (**"first phase"**) of Green Revolution spawned labor demand increases due to:

1. Shift from **broadcast to transplanting** (for weeding purposes)

2. **Cropping intensity increases** (due to seeds **<u>and</u>** H_2O)

- **"Second phase"** of Green Revolution marked by adoption of labor saving innovations (i.e., mechanical technologies) due to:

1. Rising real wages (minority of cases)

2. Direct gov't policies (overvalued XR's, subsidized credit, gasoline)

3. Availability of foreign mechanical tech.'s that don't require the adaptive research that biological technologies do (e.g., small cultivators).

4. Political influence of large farmers leads to gov't subsidization of research on mechanical technologies (e.g., Argentina, Sri Lanka)

C. Africa (Pingali, Bigot, and Binswanger)

- **Bush-fallow → (annual) Hand cultivation:** Accompanies population growth and marketization (higher rewards, produce for market)

  ⇒ Limited yield effects of mechanization

- **Hand cultivation → Animal traction:** Arises due to population density increases because labor demand rises faster than the availability of labor.

  ⇒ Animal traction is labor saving compared to hand cultivation in intensive agriculture, but not compared to hand cultivation in bush-fallow system (largely due to high labor demands for **destumping**.

- **Farming system evolution vs. choice of technique**

  ⇒ Animal to mechanical is choice of technique issue

  ⇒ Hoe to animal is farming system issue

- **TYING MECHANICAL CULTIVATION TO BIO-LOGICAL INNOVATION IS SELF-DEFEATING**

  - Biological technologies are usually labor intensive (e.g., incorporating crop residues, weeding)
  - Animal or mechanical traction is labor saving/area expanding
  - **THERE'S BEEN A TENDENCY TO TRY TO JUMP FROM BUSH FALLOW STRAIGHT TO ANIMAL TRACTION**

D. BINSWANGER'S GENERALIZATIONS (FROM W.B.R.O, 1986)

Economic Influences

1. Rate and pattern of mechanization governed by:

- Land and labor endowments
- Nonagricultural demand for labor
- Demand for ag. products

2. Mechanization most profitable where:

- Land is relatively abundant
- Labor is relatively scarce
- Labor is moving rapidly off the land

3. Mechanization <u>seldom</u> leads to yield increases (subst. view!)

4. Capital scarcity/high capital costs retard mechanization

5a. Mechanization facilitates farm consolidation (displaces tenants)

Large farms adopt machinery much faster than small farms

- Where rental markets are easily established, farm size has less influence on both size of machines and

6. Subsidies to mechanization tend to have **little effect on output**, but do **reduce employment**, and tend to favor larger farms in richer regions (**negative distributional effects**)

Patterns of Mechanization

1. When new power sources become available they are first used for operation for which their comp. advantage is greatest:

- Power-intensive operations shifted to new power sources.
- Control-intensive operations are shifted to more mechanized techniques when wages are high or rapidly rising.

2. Mechanization of power-intensive processing and pumping operations always precedes the mechanization of harvesting and crop husbandry operation, and can be profitable at low wages

3. Primary tillage is one of the first operations to be mechanized when a new source of mobile power becomes available.

Secondary tillage operations often continue to be performed by the old power source for a long period.

4. Transport, along with primary tillage, is one of the first uses of new sources of mobile power

5. Mechanization of harvesting directly depends on labor costs

Rarely profitable in low-wage countries.

Higher the control intensity of the operation, the higher must labor costs be to warrant using a machine.

6. Crop husbandry shifts to new power sources only after tillage, transport, threshing and seeding

7. In labor abundant countries, seeding of grains tends to be mechanized before grain harvesting, but the order is urually reversed when labor is scarce.