Innovation and Growth with Financial, and Other, Frictions

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Motivation

◇ The innovation and implementation of new ideas, or knowledge, are key for economic growth.

◇ Two big issues in the economics of innovation

- Production: How to achieve the optimal level of innovation?
- Exchange: How to get innovation into the hands of those best suited to implement them (technology transfer)?

◇ This process is not frictionless:

- Private sunk cost vs. long term social benefit
- Search frictions
- Bargaining frictions
- Liquidity/financial frictions

This Paper

◇ Model all these frictions explicitly, and analyze their interactions and implications for innovation and growth.

What We Do

Build a growth model where advances in knowledge lead to increases in productivity

- ◇ Individual producers have access to the frontier technology Z, which is in the public domain.
- ◇ They also come up with ideas for innovations that increase their own knowledge and productivity z.
- ◇ This new idea can also be transferred to other better implementors.
- ◇ Search, bargaining and financial frictions can impede this idea market, hindering the advancement of knowledge and economic growth.

A Short Sample of Related Work

◇ Ideas and Growth:

- Romer (1990), Jones (1997), Kortum (1997), Alvarez et al. (2008), Lucas (2009), Lucas and Moll (2011).

◇ Transfer of Ideas:

- Holmes and Schmitz (1990), Chatterjee and Rossi-Hansberg (2010), Silveira and Wright (2010), Chiu and Meh (2011).

◇ Financial Development and Growth:

- Goldsmith (1967), Greenwood and Jovanovic (1990), Levine (2004), Greenwood et al. (2008, 2010).

◇ Monetary Policy and Growth:

- Gomme (1993), Boyd and Champ (2003), Berentsen et al. (2009).

Overview

1. A New Model of Endogenous Growth
2. Technology Transfer with Perfect Credit
3. Technology Transfer with Imperfect Credit
4. Technology Transfer with Intermediation
5. Some Empirical Evidence
6. Conclusion

Basic Growth Model

Environment

- Infinite horizon: $t = 1, 2, 3, ...$
- Measure 1 of agents
- Preference:

$$u(c) - \chi h$$

- Technology

$$y = zf(H)$$

where z is **individual** productivity, H is labor demand

- Here, we abstract from physical capital, but the paper shows how to add K and get similar results.

Innovation

◇ At the beginning of each period, every agent has access to the frontier technology Z.

◇ Measure n_i agents are potential innovators, coming up with a new idea every period.

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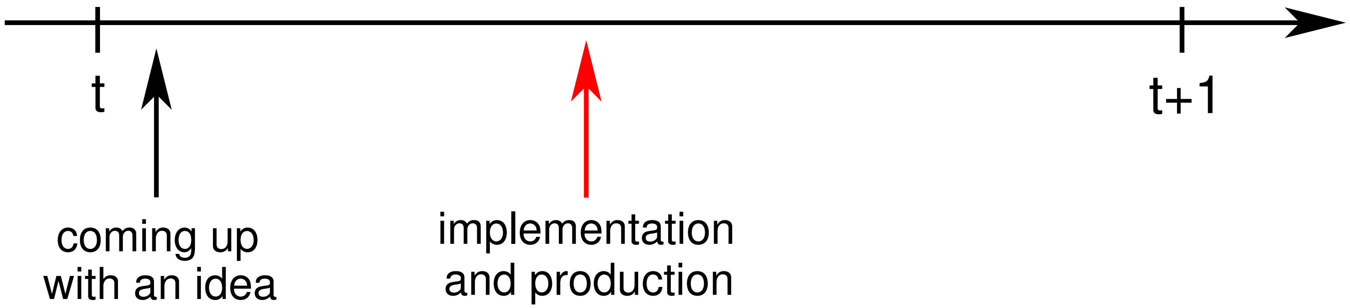
Innovation

- ◇ At the beginning of each period, every agent has access to the frontier technology Z.
- ◇ Measure n_i agents are potential innovators, coming up with a new idea every period.
- ◇ They try to implement their ideas to improve individual productivity z.



Idea Implementation

◇ Successful idea implementation can improve individual productivity:

$$z = \begin{cases} Z(1+\eta) & \text{w/prob. } \sigma \\ Z & \text{w/prob. } 1-\sigma \end{cases}$$

where Z is frontier productivity, and z is individual productivity **after** implementation

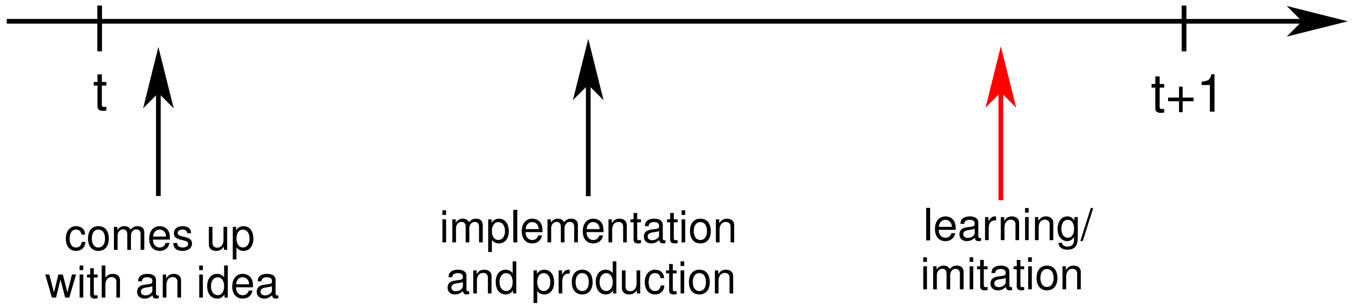
◇ $\sigma \sim F_i(\sigma)$ captures the match between idea and agent's skill

◇ Successful implementation increases individual profit in the short run

Diffusion

◇ At end of the period, knowledge will enter the public domain, freely available to other agents to imitate/learn

◇ All agents start the next period with same frontier technology Z_{t+1}



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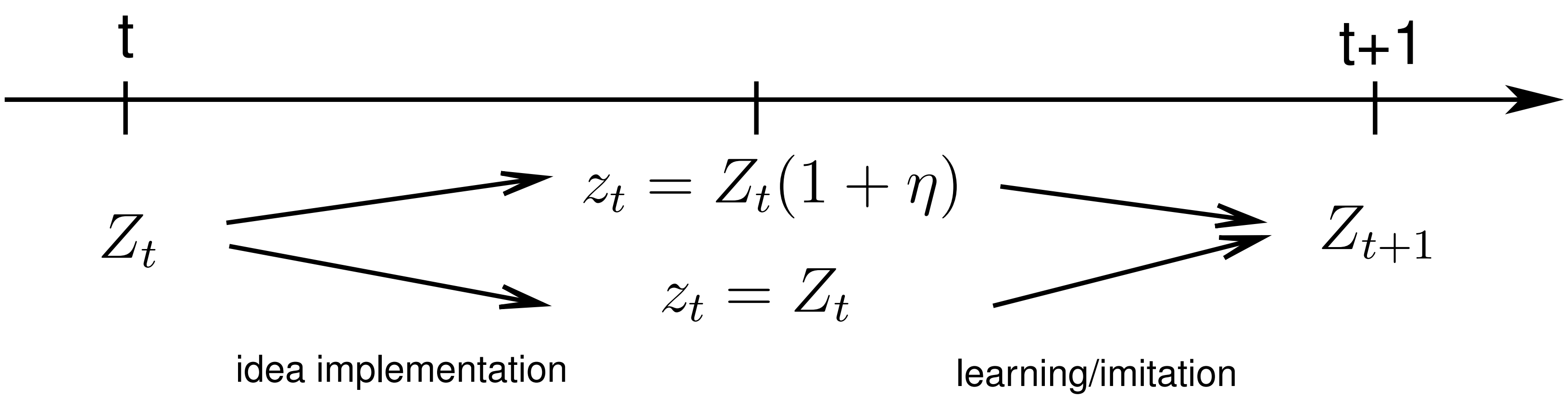

Diffusion (Cont'd)

In general, we assume a learning/imitation process where Z_{t+1} is increasing in the productivity $z_t(j)$ of all individuals.

An Example

$$Z_{t+1} = \rho \left[\int_0^1 z_t(j)^{\varepsilon} dj \right]^{\frac{1}{\varepsilon}},$$

where

z_t is individual productivity at the end of t

Z_{t+1} is frontier productivity at the beginning of $t+1$

Example (Cont'd)

$$Z_{t+1} = \rho \left[\int_0^1 z_t(j)^{\varepsilon} dj \right]^{\frac{1}{\varepsilon}},$$

- When $\varepsilon = \infty$, frontier technology is determined by the most productive agent.
- When $\varepsilon = -\infty$, frontier technology is determined by the least.
- When $\varepsilon = 1$, frontier technology is the average of all agents'.

Real Asset

- ◇ To facilitate later discussion, introduce a fixed stock A of real asset.
- ◇ Each share, a, has a price ϕ and yields dividend δ.
- ◇ Dividend δ can be turned into $Z\delta$ consumption good (to help generate balanced growth).

Balanced Growth Path

Aim to construct the BGP s.t.

- $1 + g = \frac{Z_{t+1}}{Z_t} = \frac{Y_{t+1}}{Y_t} = \frac{C_{t+1}}{C_t} = \frac{w_{t+1}}{w_t} = \frac{\phi_{t+1}}{\phi_t}$.
- Utility function: $u(c) = \log(c)$

Agent's Problem

After z is realized, each agent solves:

$$W(a, z; Z) = \max_{c,h,a'} \{u(c) - \chi h + \beta V(a', Z')\}$$

subject to

$$c + \phi a' = wh + (\phi + \delta Z)a + \pi(z), \pi(z) = \max_{H} \{zf(H) - wH\},$$

$$V(a, Z) = \int_0^1 \sigma W(a, Z(1 + \eta); Z) + (1 - \sigma)W(a, Z; Z)dF_i(\sigma).$$

Return to implementation

Expected gain from implementing an idea with σ

$$\sigma \Delta \equiv \sigma \underbrace{(\pi_1 - \pi_0) \frac{\chi}{w}}_{\Delta},$$

where

π_1 is the profit for high productivity agents,

π_0 is the profit for low productivity agents.

Equilibrium

Equilibrium consists of prices (ϕ, w) and quantities (c_j, h_j, H_j, a'_j) for each agent j such that

1. Given prices, quantities solve the maximization problem of each j.

2. Market clearing conditions are satisfied

$$
\begin{aligned}
\int_0^1 c_j dj &= \int_0^1 z_j f(H_j) dj + AZ\delta \\
\int_0^1 H_j dj &= \int_0^1 h_j dj \\
\int_0^1 a'_j dj &= A
\end{aligned}
$$

Result

Let N be the measure of ideas successfully implemented.

$$N = n_i \mathbb{E}\sigma = n_i \int_0^1 \sigma dF_i(\sigma)$$

The equilibrium growth rate of the economy is $1 + g = G(N)$.

In the example, $1 + g = \rho \left[N(1+\eta)^{\varepsilon} + (1 - N) \right]^{1/\varepsilon}$.

Endogenous Innovation

- Suppose potential innovators have to pay cost κ_i to come up with ideas.

- Free entry equates innovation cost to the expected (private) gain.

$$n_i = \begin{cases} 0 & \text{if } \kappa_i > \bar{\kappa}_i \\ [0, \bar{n}_i] & \text{if } \kappa_i = \bar{\kappa}_i \\ \bar{n}_i & \text{if } \kappa_i < \bar{\kappa}_i \end{cases}$$

where $\bar{\kappa}_i = \Delta \chi \mathbb{E} \sigma / \bar{w}$ is the expected gain from an innovation.

Result

- *Growth rate depends on*
  - ◇ *entry cost of innovators* (κ_i)
  - ◇ *matching distribution between ideas and agents* (F_i)
  - ◇ *quality of innovation* (η)
  - ◇ *diffusion technology* (ρ, ε)
- *Growth rate does not dependent on* $A\delta$

Proposition

- *There exists a unique equilibrium with balanced growth at rate $1 + g = G(N)$ with $N = n_i \mathbb{E}\sigma$.*

- *With endogenous innovation, equilibrium is generally inefficient.*

- *The optimal policy involves a subsidy*

$$\tau_i = \frac{G'(N)\mathbb{E}\sigma}{G(N)r} > 0.$$

Tech Transfer with Perfect Credit

Entrepreneurs

- Introduce measure n_e of entrepreneurs (endogenize later)
- Entrepreneurs do not innovate.
- But potentially better at implementing ideas: $\sigma_e \sim F_e(\sigma_e|\sigma_i)$.

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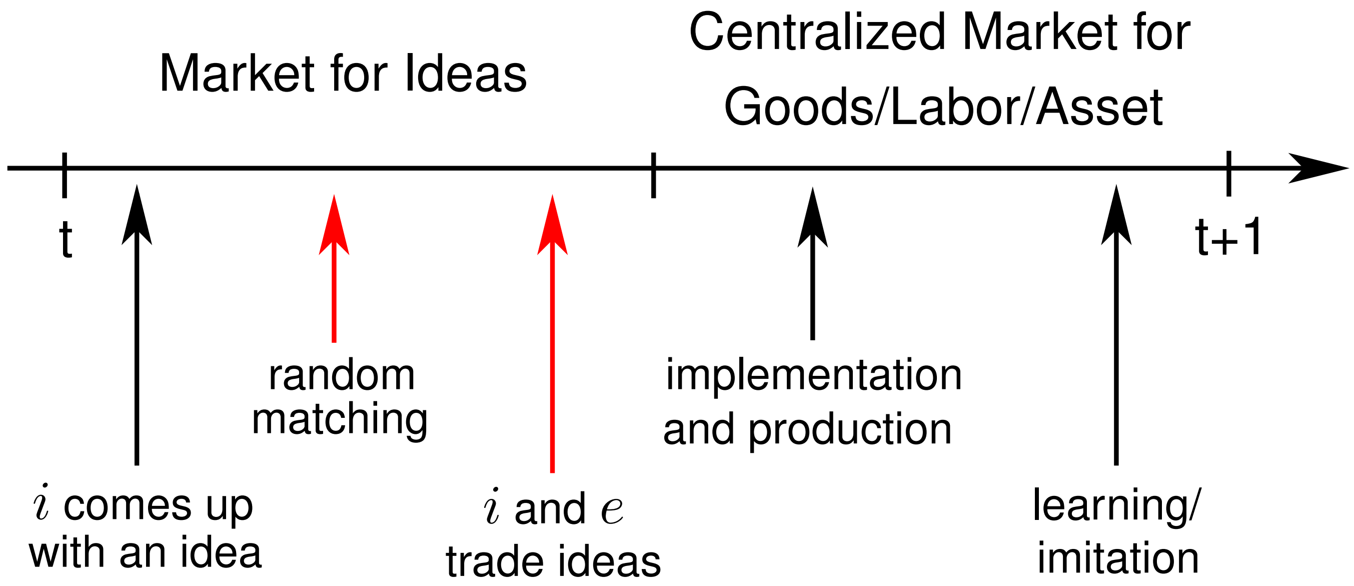


Market for Ideas with Perfect Credit

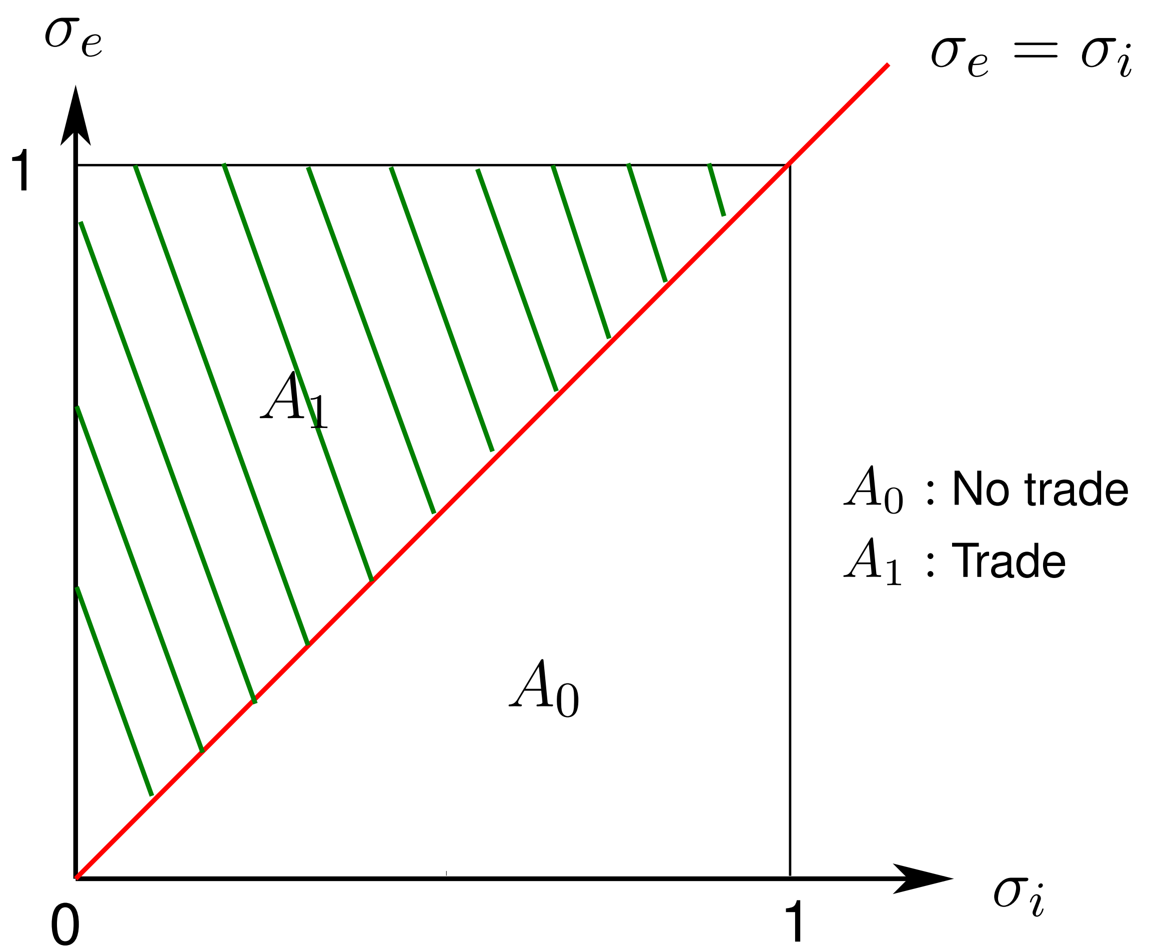
◇ Bilateral random matching:

– e meets with i w/prob α_e, and i meets with e w/prob α_i

◇ Terms of trade determined by Nash bargaining.

$$\max_p \left[\sigma_e \Delta - p\right]^\theta \left[p - \sigma_i \Delta\right]^{1-\theta}$$

$$\Rightarrow p(\sigma_e, \sigma_i) = \Delta[\theta\sigma_i + (1-\theta)\sigma_e]$$



An idea is traded whenever $\sigma_e > \sigma_i$.

Result

◇ Growth rate is still $1 + g = G(N)$.

◇ Only difference is more ideas are successfully implemented:

$$N = \mathbb{E}\sigma_i + \underbrace{n_e \alpha_e \hat{\mathbb{E}}(\sigma_e - \sigma_i)}_{\text{Additional success due to trade}},$$

where $\hat{\mathbb{E}}(\sigma_e - \sigma_i) = \mathbb{E}(\sigma_e - \sigma_i | \sigma_e > \sigma_i) \Pr(\sigma_e > \sigma_i)$.

Two Sided Entry

- Endogenize n_i as before. Endogenize n_e by assuming e has to pay cost κ_e to enter the idea market.

- The measures of active innovators n_i and entrepreneurs n_e satisfy

$$n_j = \begin{cases} 0 & \text{if } \kappa_j > \bar{\kappa}_j \\ [0, \bar{n}_j] & \text{if } \kappa_j = \bar{\kappa}_j \\ \bar{n}_j & \text{if } \kappa_j < \bar{\kappa}_j \end{cases} \quad \text{for } j = i, e$$

  where $\bar{\kappa}_i = u'(c)Z\Delta[\mathbb{E}\sigma_i + (1-\theta)\frac{\mu(n_i,n_e)}{n_i}\hat{\mathbb{E}}(\sigma_e - \sigma_i)]$ and $\bar{\kappa}_e = u'(c)Z\Delta\theta\frac{\mu(n_i,n_e)}{n_e}\hat{\mathbb{E}}(\sigma_e - \sigma_i)$ are the expected gains.

Result

- *Transferring ideas increases growth.*

- *Growth rate depends on*
  - ◇ *entry costs of innovators and entrepreneurs* (κ_i, κ_e)
  - ◇ *matching distribution between ideas and agents* (F_i, F_e)
  - ◇ *quality of innovation* (η)
  - ◇ *diffusion technology* (ρ, ε)
  - ◇ *matching frictions between agents* (α_i, α_e)
  - ◇ *bargaining power* (θ)

- *Growth rate does not depend on* $A\delta$

Proposition

- *With two-sided entry, there exists a unique interior equilibrium as long as κ_i, κ_e are neither too high nor too low.*

- *Equilibrium is generally inefficient.*

- *The optimal policies satisfy the modified Hosios conditions*

$$\begin{aligned}
\tau_e &= \frac{G'(N)\mu_e\hat{\mathbb{E}}(\sigma_e-\sigma_i)}{rG(N)} - u'(c)\, Z\Delta\hat{\mathbb{E}}(\sigma_e-\sigma_i)\left[\theta\frac{\mu}{n_e}-\mu_e\right] \\
\tau_i &= \frac{G'(N)[\hat{\mathbb{E}}\sigma_i+\mu_i\hat{\mathbb{E}}(\sigma_e-\sigma_i)]}{rG(N)} - u'(c)\, Z\Delta\hat{\mathbb{E}}(\sigma_e-\sigma_i)\left[(1-\theta)\frac{\mu}{n_i}-\mu_i\right].
\end{aligned}$$

Tech Transfer with Imperfect Credit

Liquidity

◇ Suppose a fraction $A_1 = \gamma A$ of the assets are *liquid*: can be traded in the idea market. Remaining $A_0 = (1-\gamma)A$ are illiquid.

◇ The rate of return on liquid asset is $1 + r_1 = \frac{\phi' + Z'\delta}{\phi}$.

◇ The rate of return on illiquid asset is $1 + r_0 = \frac{1+g}{\beta}$.

◇ Define the spread, or *liquidity premium*, by

$$s = \frac{r_0 - r_1}{1 + r_1},$$

measuring the cost of holding liquidity.

Bargaining Problem

◇ Entrepreneur brings $x = \frac{\phi + Z\delta}{Z} a_1$ liquid asset to the idea market.

◇ Liquidity constraint: $p \leq x$

◇ Bargaining problem becomes

$$\max_{p \leq x} \left(-p + \sigma_e \Delta\right)^{\theta} \left(p - \sigma_i \Delta\right)^{1-\theta},$$

◇ If $x \leq \sigma_i \Delta$, not enough liquidity to cover the reservation price.

◇ Liquidity constraint binds if

$$\sigma_e \leq B(\sigma_i, x) \equiv \frac{1}{1-\theta}\left[\frac{x}{\pi_1 - \pi_0} - \theta\sigma_i\right].$$

◇ **Bargaining Outcome**

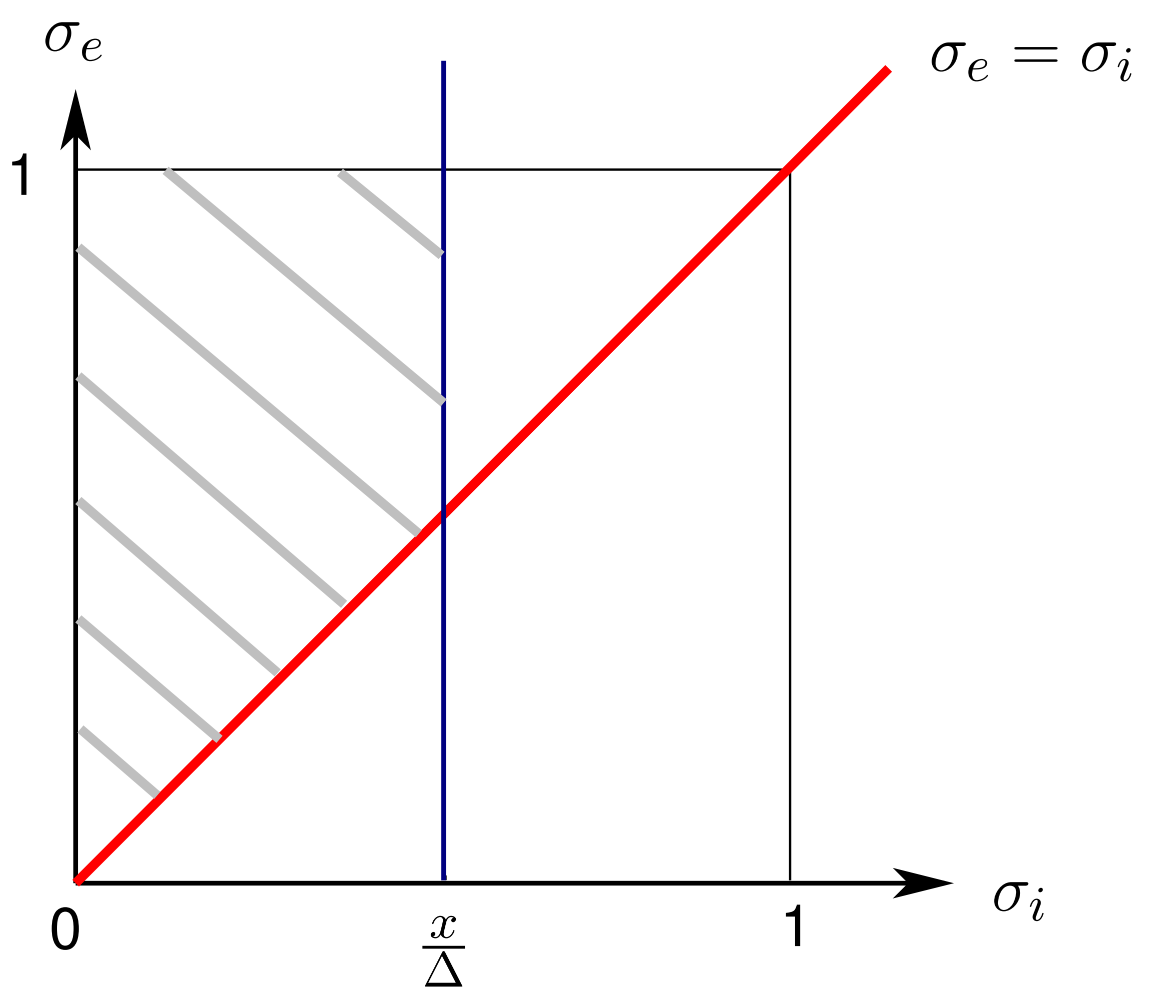
If $\sigma_e < \sigma_i$: no gains from trade.

If $\sigma_e \geq \sigma_i$: gains from trade.

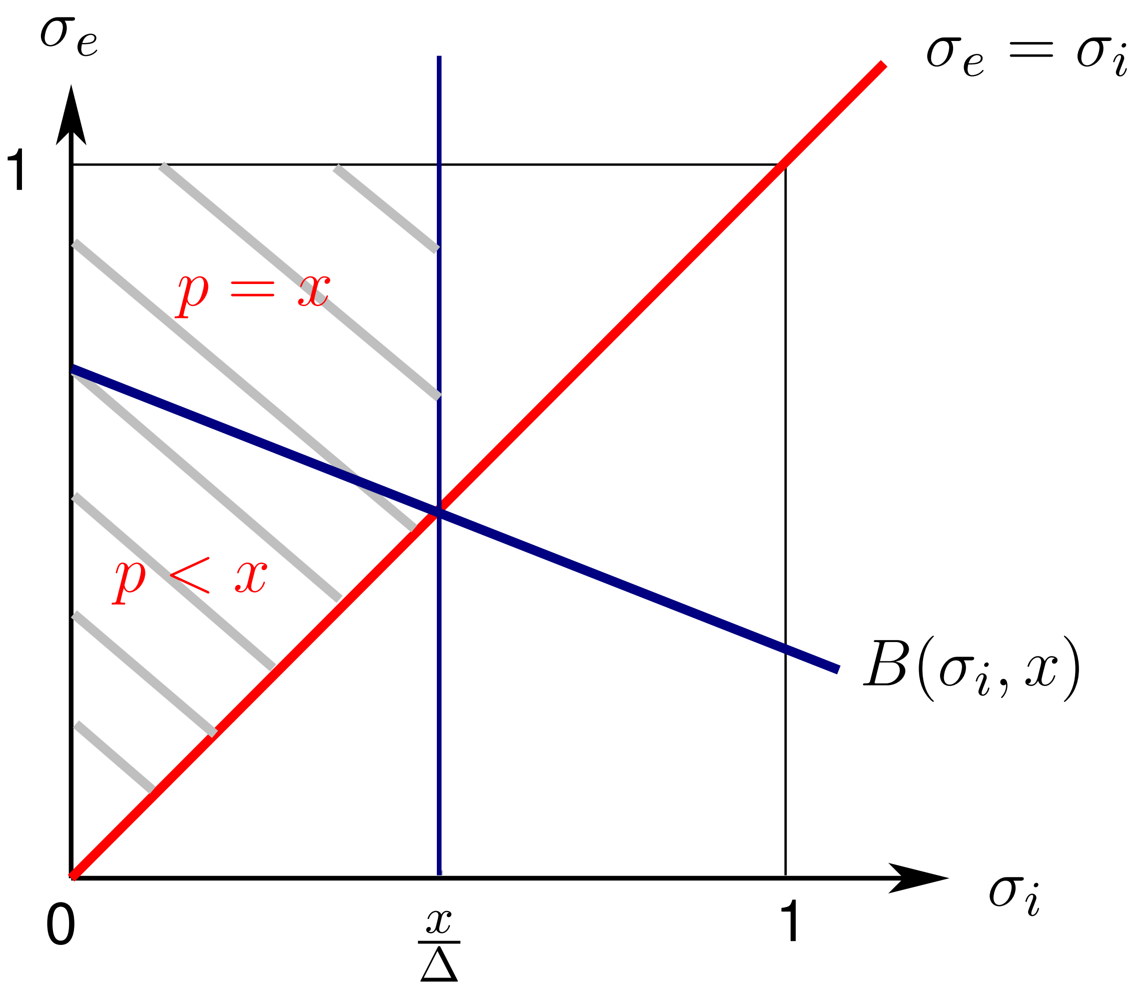
(i) no trade when $\sigma_i > \frac{x}{\Delta}$: insufficient liquidity

(ii) trade at $p < x$ when $\sigma_e \leq B(\sigma_i, x)$ and $\sigma_i \leq \frac{x}{\Delta}$.

(iii) trade at $p = x$ when $\sigma_e > B(\sigma_i, x)$ and $\sigma_i \leq \frac{x}{\Delta}$.



◇ An idea is traded iff $\sigma_e \geq \sigma_i$ AND $\frac{x}{\Delta} \geq \sigma_i$.



◇ An idea is traded iff $\sigma_e \geq \sigma_i$ AND $\frac{x}{\Delta} \geq \sigma_i$.

◇ Note: x and Δ are endogenous objects determined in GE.

Result

- Growth rate is still $1 + g = G(N)$
- Number of ideas successfully implemented is

$$N = \mathbb{E}\sigma_i + \underbrace{n_e \alpha_e \hat{\mathbb{E}}(\sigma_e - \sigma_i)}_{\text{Additional success due to trade}},$$

where

$$\hat{\mathbb{E}}(\sigma_e - \sigma_i) = \mathbb{E}(\sigma_e - \sigma_i | \min\{\sigma_e, \tfrac{x}{\Delta}\} > \sigma_i) \Pr(\min\{\sigma_e, \tfrac{x}{\Delta}\} > \sigma_i)$$

Result

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  - ◇ *quality of innovation* (η)
  - ◇ *diffusion technology* (ρ, ε)
  - ◇ *matching frictions between agents* (α_i, α_e)
  - ◇ *bargaining power* (θ)
  - ◇ *supply of liquidity* ($A_1\delta$)

Result

Effect of Liquidity (for fixed participation)

◇ *Exogenous reduction in the* ***supply of liquid asset*** $A_1\delta$

- *higher liquidity premium* (s)
- *less liquidity* (x)
- *fewer ideas traded and implemented* (N)
- *lower output* (Y)
- *lower wage* (w)
- ***lower growth*** (g)

Result

Effect of bargaining power (for fixed participation)

◇ *Increase in the* ***entrepreneurs' bargaining power*** θ

- *higher liquidity premium* (s)
- *higher liquidity* (x)
- *more ideas traded and implemented* (N)
- *higher wage* (w)
- *higher output* (Y)
- ***higher growth*** (g)

Proposition

- *With endogenous innovation, there exists an interior equilibrium as long as κ_i is not too high nor too low.*
- *Equilibrium is generally inefficient, unless:*
  - ◇ *The subsidy is set to*

$$\tau_i = \frac{G'(N)[\hat{\mathbb{E}}\sigma_i + \mu_i\hat{\mathbb{E}}(\sigma_e - \sigma_i)]}{rG(N)} - u'(c)\, Z\Delta\hat{\mathbb{E}}(\sigma_e - \sigma_i)\left[(1-\theta)\frac{\mu}{n_i} - \mu_i\right];$$

  - ◇ *The supply of liquid assets is abundant $\gamma A\delta \geq A^*$;*
  - ◇ *Entrepreneurs have all the bargaining power, $\theta = 1$.*

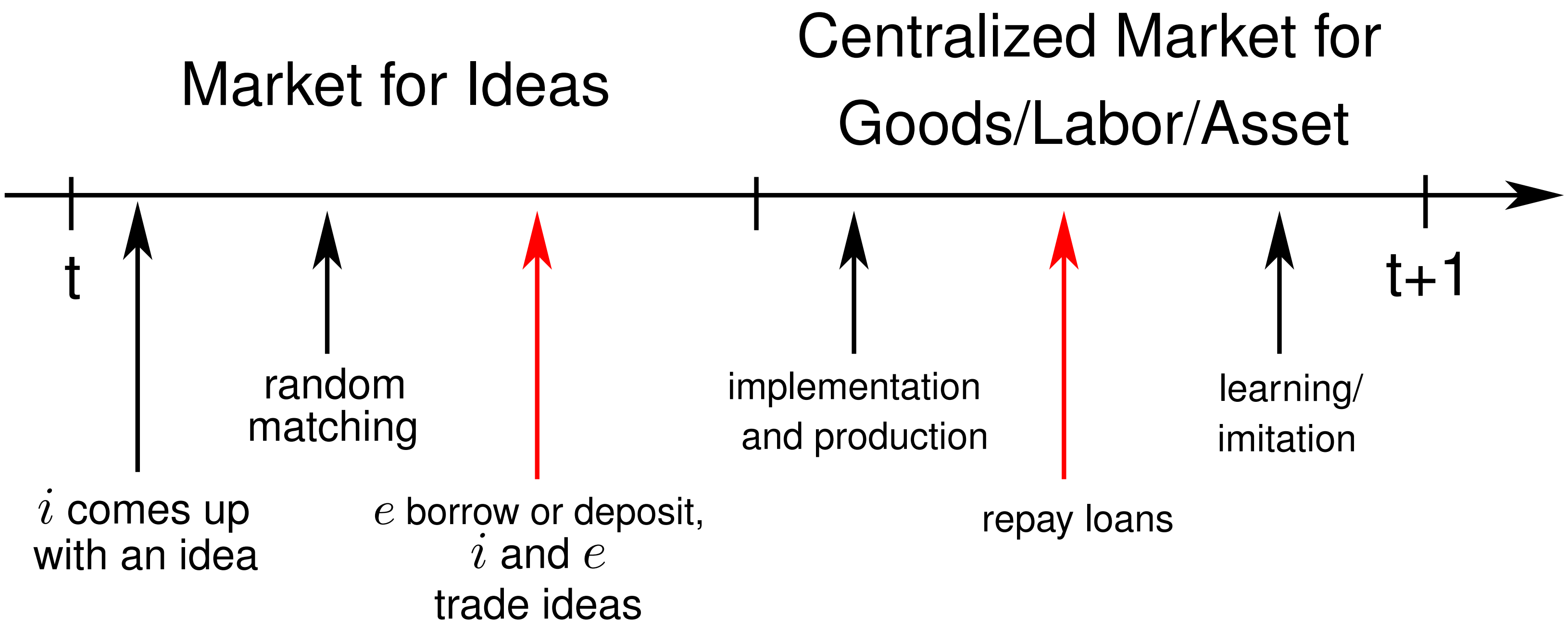
Tech Transfer with Intermediation

Financial Intermediation

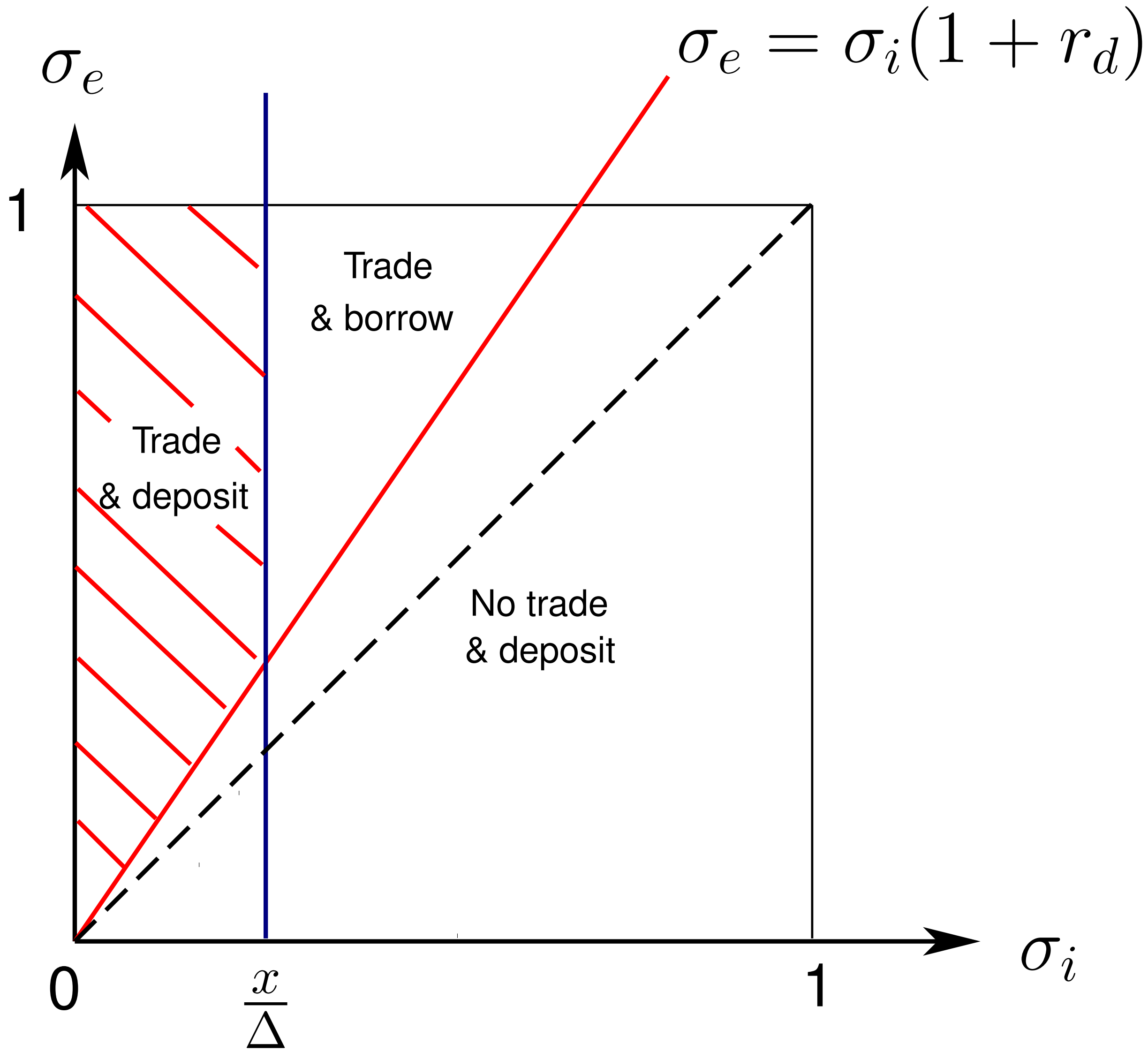
- Competitive financial intermediaries take deposits and make loans of liquid assets at interest rate r_d.

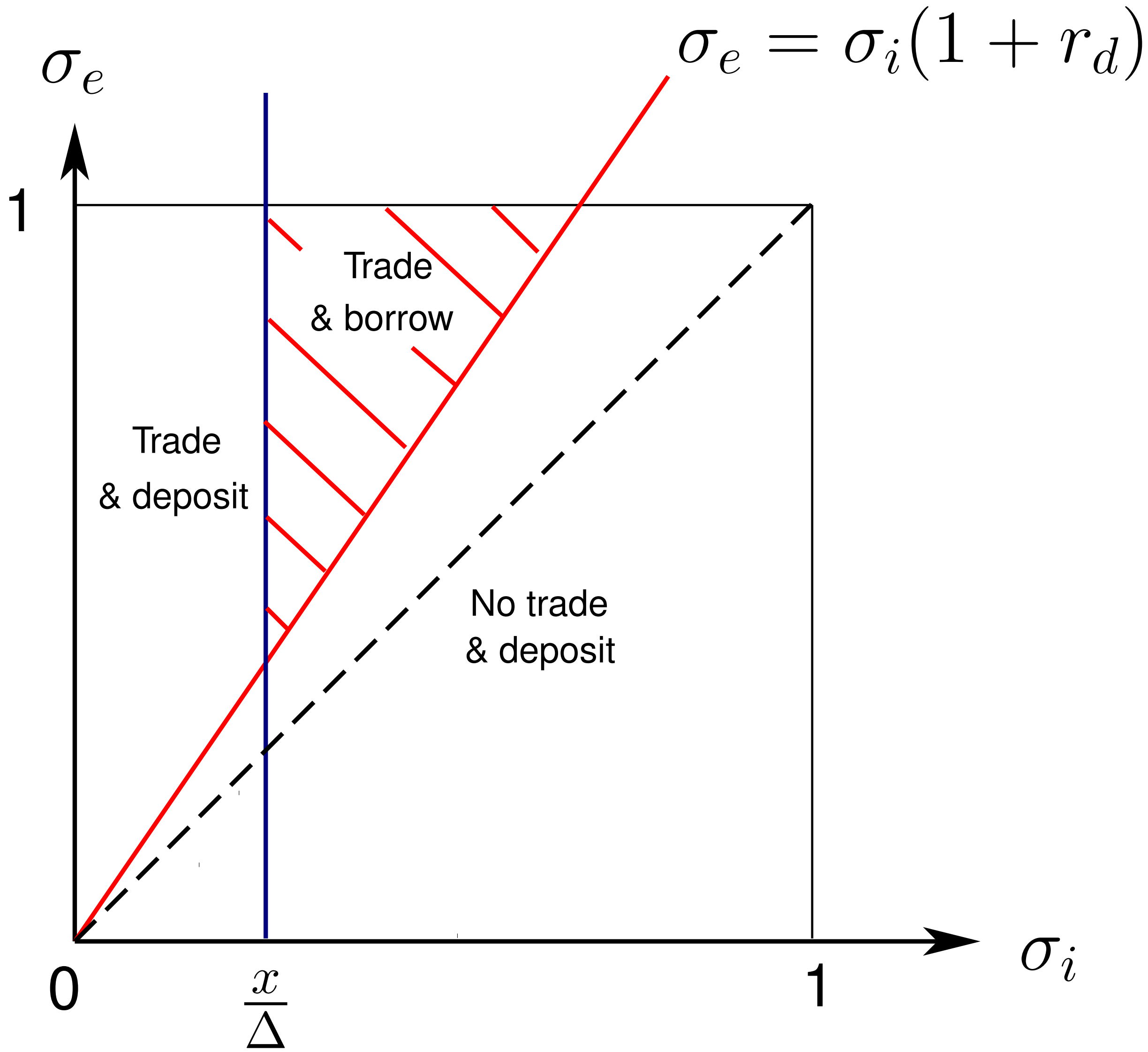
- Financial intermediaries have a record-keeping technology to keep financial record of entrepreneurs. (Berentsen et al., JET 2007)

◇ After meeting and observing the realization of (σ_i, σ_e), an entrepreneur can lend to/borrow from an intermediary. Loans repaid in the next centralized market.



Market for Ideas
Centralized Market for
Goods/Labor/Asset
t
t+1
i comes up
with an idea
random
matching
e borrow or deposit,
i and e
trade ideas
implementation
and production
repay loans
learning/
imitation


$\sigma_e = \sigma_i(1 + r_d)$
σ_e
1
Trade
& borrow
Trade
& deposit
No trade
& deposit
0
$\frac{x}{\Delta}$
1
σ_i



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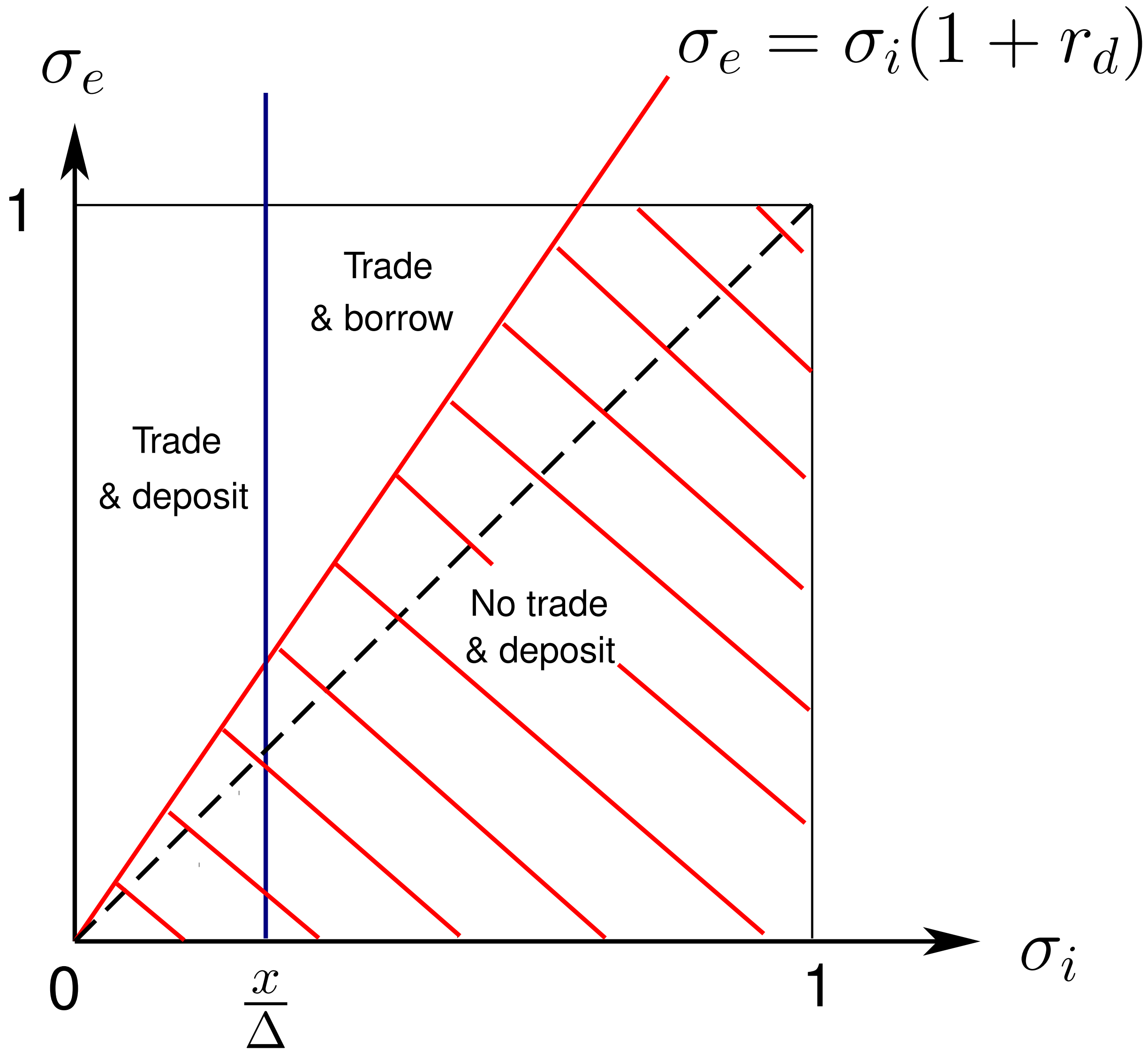
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  - ◇ *bargaining power* θ

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- *There exists an equilibrium with fixed* n_i, n_e.
- *With endogenous innovation, equilibrium is inefficient, unless:*
  - ◇ *The subsidy is set as in the previous proposition;*
  - ◇ *The supply of liquid assets is abundant* $\gamma A\delta \geq A^{**}$.

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Remark: Intermediation improves allocation by

(i) economizing on the usage of scare liquid assets ($A^{**} < A^{*}$)

(ii) eliminating the holdup problem (we no longer require $\theta = 1$)

Some Evidence

- Sample: Firm level data from the World Bank Enterprize Surveys (4059 firms across 33 countries in 2002-2005)
- Study the effects of financial development on a firm's decision to transfer technology
  - Ratio of private credit to GDP as proxy for financial development
  - Other controls variables include market & firm size, price & level of investment, openness and industry dummies
  - OLS, 2SLS and Probit regressions

Some Evidence (Cont'd)

Main findings:

1. In some countries (e.g., Germany), direct technology transfers from outside parties are an important way for firms to acquire new technology.

2. Firms' decision to transfer technology is positively correlated with the financial development in a country, particularly for small firms.

Some Evidence (Cont'd)

- The empirical literature also finds that firms' technology transfer depends on their own cash holding and access to bank loans.

- For example, Montalvo and Yafeh (1994) examine investment in foreign technology by Japanese firms and conclude that "liquidity is an important consideration in the firm's decision to invest in foreign technology."

Conclusion

- Developed a novel, tractable endogenous growth model in which advances in knowledge lead to increases in productivity.

- Showed how this process is aided by the exchange of ideas, and how search, bargaining, and financial frictions can impede this market, hindering economic growth.

- Characterize optimal tax-transfer policies to subsidize research and trade in ideas, given knowledge and search externalities.

- Analyze the role of financial intermediation in mitigating liquidity and holdup problems in bargaining.

What is an Idea?

1. Inputs into the expansion of knowledge, improving productivity.

2. Ideas are indivisible – either I tell you or I don't (mainly a technical consideration).

3. Ideas is non-rival goods at least in the long run when knowledge enters the public domain (can be non-rival in the short run too).

4. Ideas are difficult to collateralize, making credit problematic and motivating the consideration of liquidity.

5. The idea market is rife with information problems, motivating a general desire to transfer ideas directly.

Innovation and Technology Markets

Lamoreaux and Sokoloff examined US patent history in 1840-1920 and argued

> *"There is, in our view, good reason to believe that it was the expanded opportunities to trade in the rights to patented technologies that enabled the independent inventors of this golden age to flourish, and that stimulated the growth of inventive activity more generally. Early nineteenth-century inventors generally took personal responsibility for the commercial development of their ideas, making it difficult for them to focus exclusively on the generation of new technologies. As institutions emerged to facilitate the sale or transfer of patent rights to other individuals or firms better positioned to commercially exploit them, however, many inventors increasingly took advantage of this avenue for extracting the returns to their efforts and concentrated*

on inventive activity. In other words, the growth of market trade in patents raised the returns to invention generally, and encouraged a division of labor whereby technologically creative individuals increasingly specialized in their comparative advantage – invention.”

– Lamoreaux and Sokoloff (1999)

Search Cost in Technology Markets

"... the growth of technology trade in the United States in the nineteenth century was accompanied and sustained by the growth of patent attorneys, patent agents, and other services that helped bring buyers and sellerstogether. Patent databases and smart tools for searching these databases and using the knowledge contained in them are another means for ***reducing search costs in the market for technology****."*

– Arora et al. (2001)