

Strategic Concealment in Innovation Races

Midwest Theory Conference

Yonggyun (YG) Kim

Florida State University

Francisco Poggi

University of Mannheim

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Introduction

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- **Innovation races**
 - Multiple firms race toward developing an innovative product
 - There is a premium for being the first to market
- **Multiple stages of innovation**
 - Developing the product often involves a sequence of technological breakthroughs
- **Multiple innovation paths**
 - Examples:
 - COVID-19 vaccine: mRNA or viral vector
 - Full Self-driving (FSD) vehicle: Camera or LIDAR
 - Firms R&D strategies involve which path to take

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 - COVID-19 vaccine: mRNA or viral vector
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Main Questions

- **Q1:** How do firms' strategic R&D decisions hinge on information about their competitors' innovation status?
 - Firm A may adjust its innovation path depending on Firm B's status
⇒ It creates an incentive for Firm B to conceal its advancement
 - However, keeping it secret carries the risk of losing the right when the other firm files the patent
- **Q2:** When do firms conceal their interim breakthroughs, and how does it affect the social speed of innovation?
 - Reward of winning the race
 - Trade secret protection level (first-to-invent vs. first-to-file patent system)

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Model

Model: Preliminaries

- Two risk-neutral firms $i \in \{A, B\}$ race to develop an innovative product
- Continuous and infinite time $t \in [0, \infty)$
- Two technologies to develop the product:
 - An **old** technology L
 - A **new** technology H (*not accessible at the beginning*)
- At t , each firm (w/o new technology) allocates a unit of resources to:
 - Research σ_t^i
 - Development $(1 - \sigma_t^i)$
- Resource allocation is not observable to the rival firm

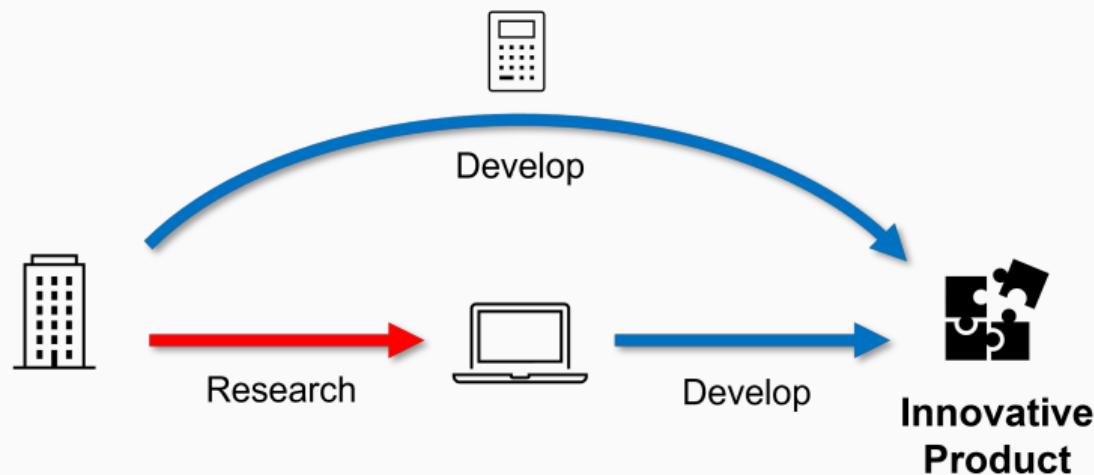
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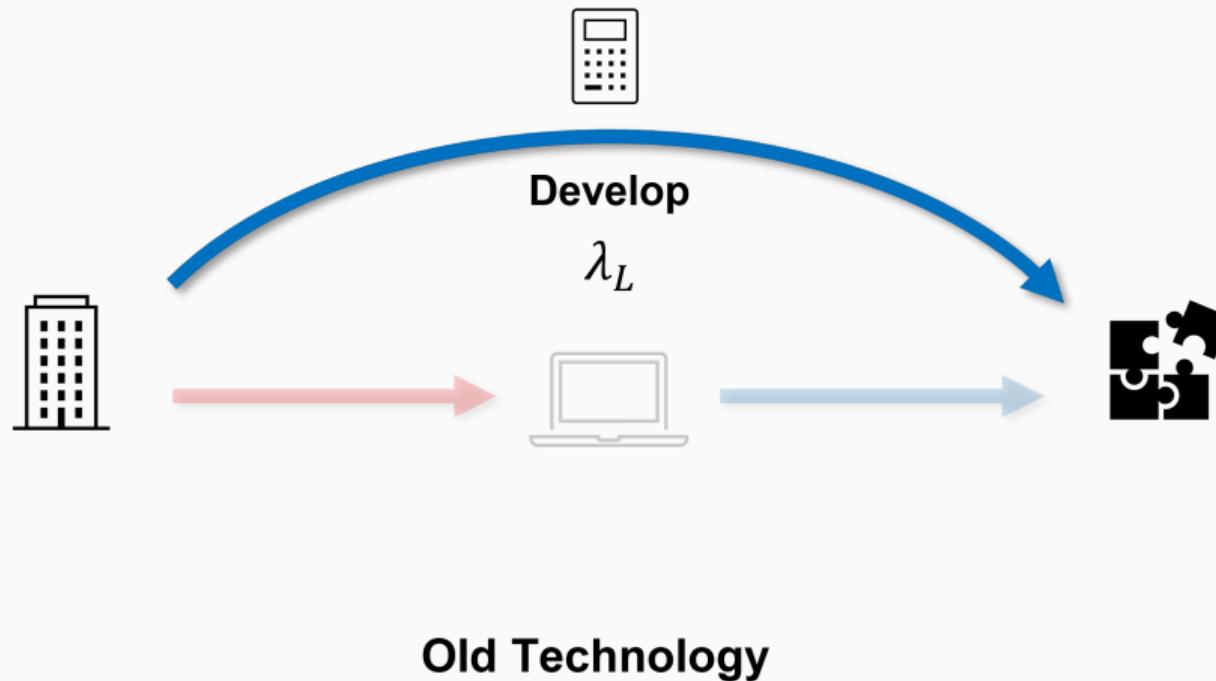
Model: Technology Illustrations

- Two paths toward the product development

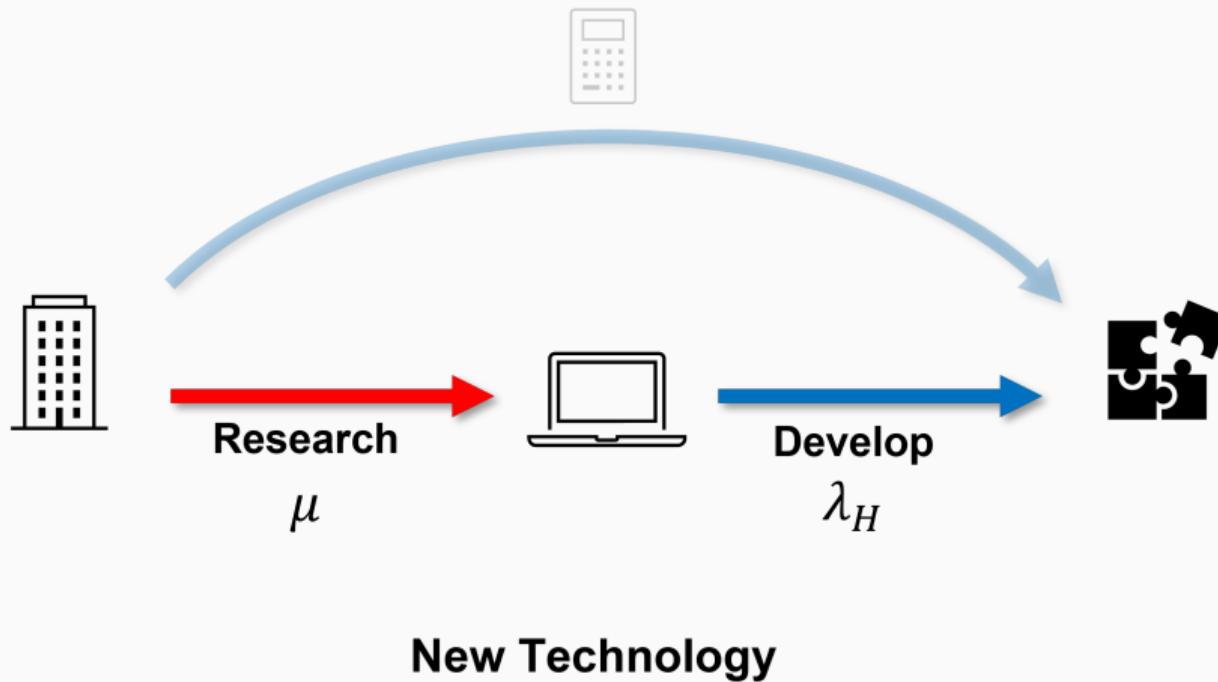
▶ Further Examples



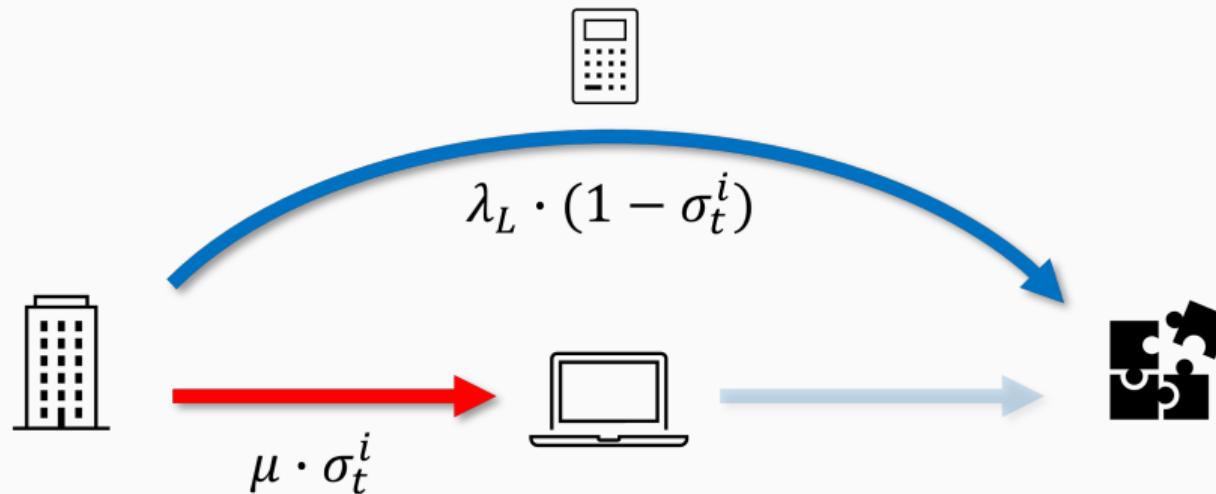
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Model: Technology Illustrations



Partial Allocation

Model: Payoffs

- The first firm to successfully develop the innovative product receives Π
 - e.g., Π is a transitory monopoly profit
- The rival firm gets zero and the race stops
- Firms pay a flow cost c until the race stops
- Firms do not discount the future
- Thus, the final payoff of Firm i is:

$$\mathbb{1}_{\{i \text{ develops the product first}\}} \cdot \Pi - c \cdot T$$

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Model: Parametric Assumptions

1. The new technology path ($R + D$) is more efficient than the old technology path:

$$\Pi - \frac{1}{\mu} - \frac{1}{\lambda_H} > \Pi - \frac{1}{\lambda_L} \iff \frac{1}{\lambda_L} > \frac{1}{\mu} + \frac{1}{\lambda_H}$$

- If there were no race, a firm would follow the new technology path

2. Developing with the old technology is profitable:

$$\Pi \geq \frac{c}{\lambda_L}$$

- This assumption ensures that a firm never exits even if it finds out that the rival is ahead of the race

► Low-Reward Case

► First-Best Outcome

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Benchmark: Constant Development Rate

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- Suppose that Firm j develops the product at a constant rate λ
- Define

$$\lambda_* \equiv \mu\lambda_H \left(\frac{1}{\lambda_L} - \frac{1}{\mu} - \frac{1}{\lambda_H} \right) > 0. \quad (1)$$

Proposition 1

Suppose that Firm j 's development rate is λ :

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- if $\lambda > \lambda_*$, Firm i develops with the old technology.

► iso-development-rate curve

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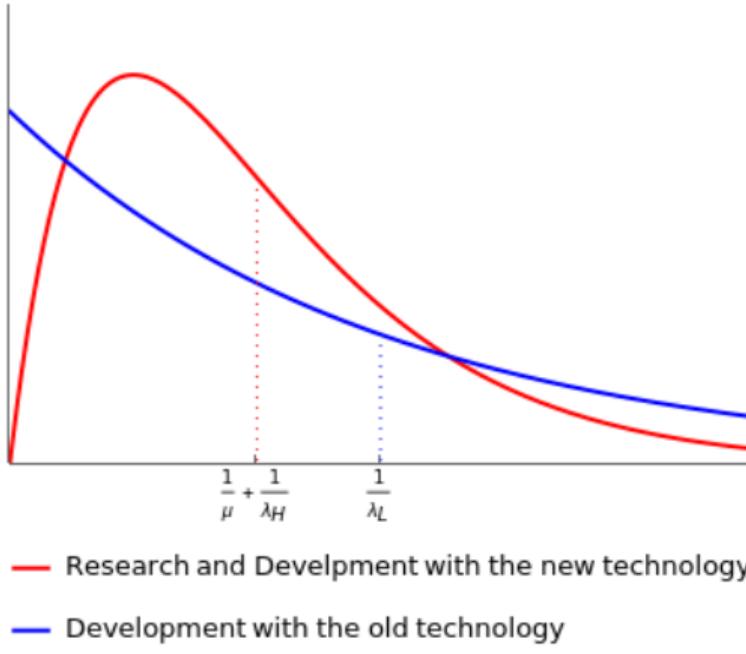
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Comparison between two paths



PDF of the completion time without race

Long Run:

- By comparing the expected completion time:
 $\text{Research} \succ \text{Development}$

Short Run:

- By comparing the prob. of completion in the near future:
 $\text{Research} \prec \text{Development}$

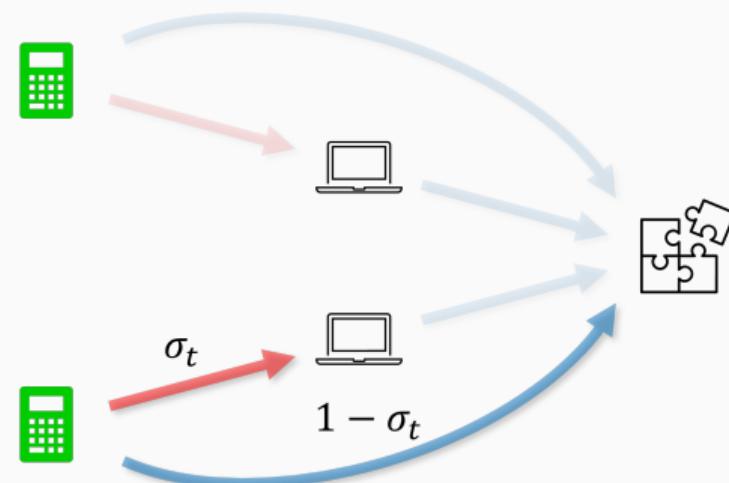
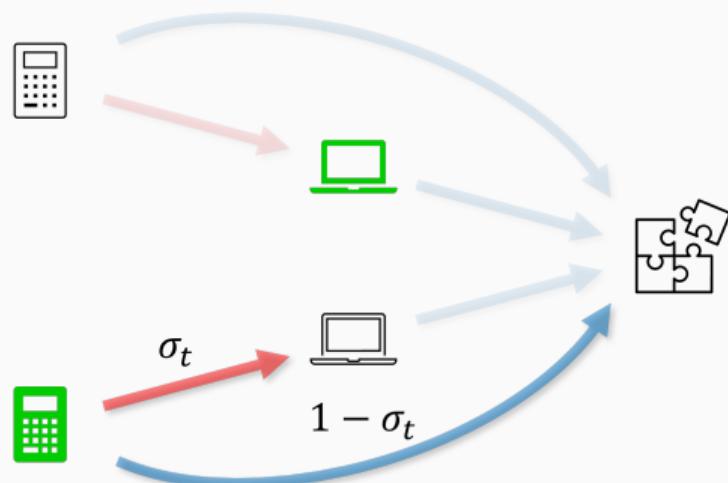
Public Information Setting

Public Information Setting

- **Strategy:** resource allocations over time contingent on the rival's status
- **Markov strategy**

► Formal Definitions

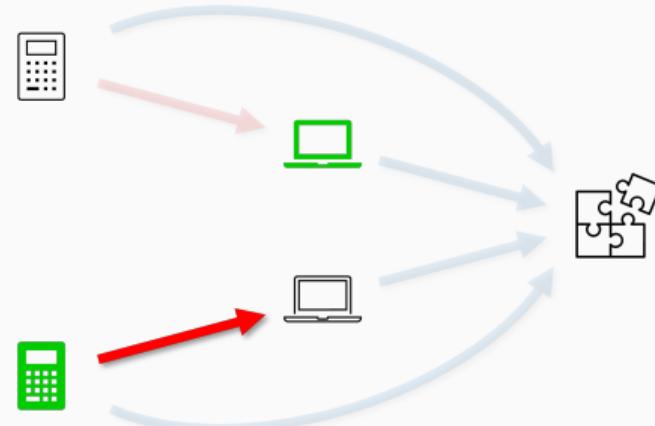
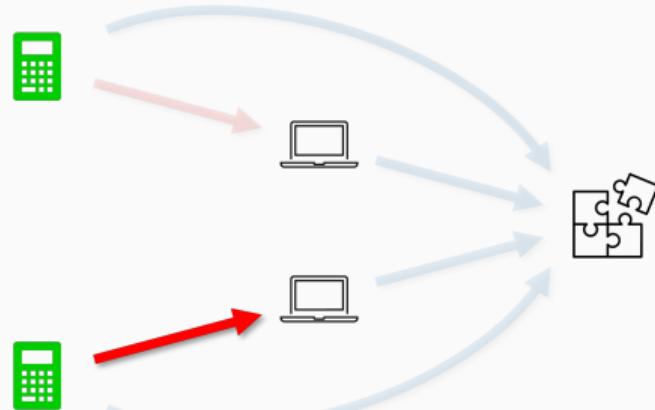
- State variable: whether the rival has the new technology or not



Benchmark Strategy 1: Research Strategy

Research Strategy

- Do research regardless of the rival's progress

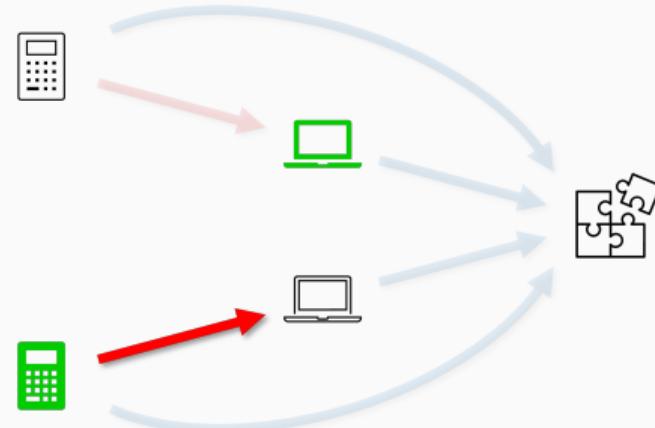
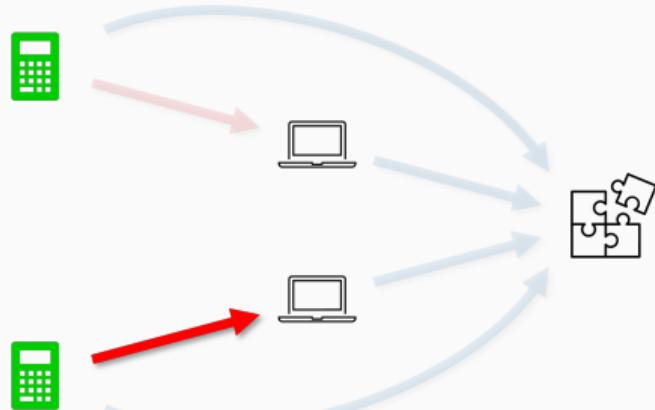


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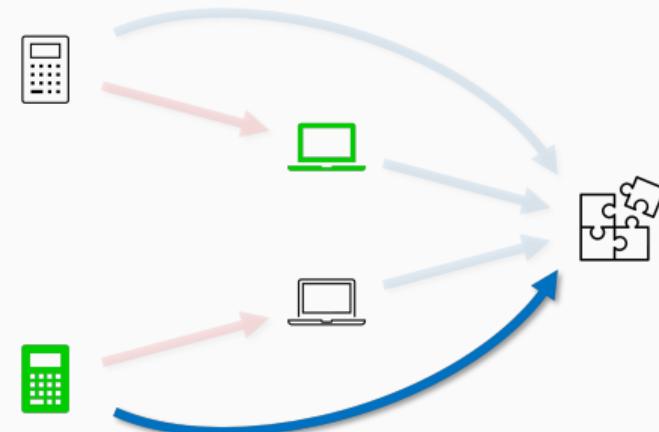
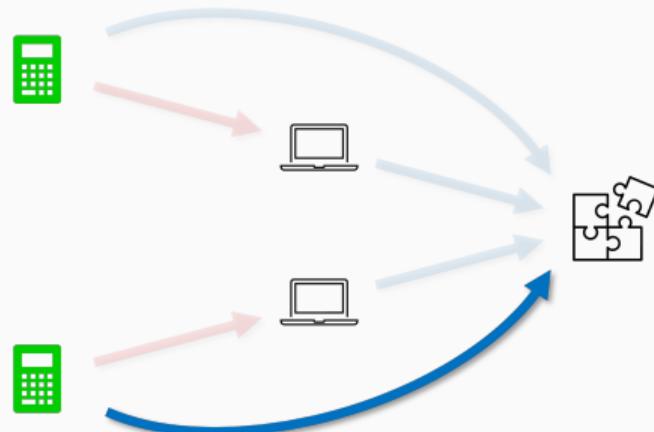


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Benchmark Strategy 2: Direct-Development Strategy

Direct-Development Strategy

- Develop with the old technology regardless of the rival's progress

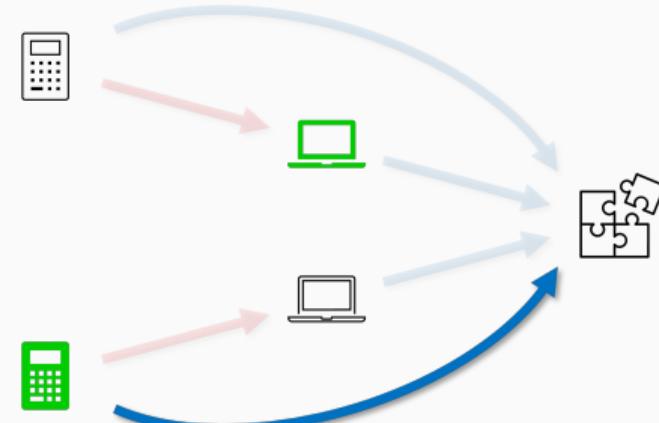
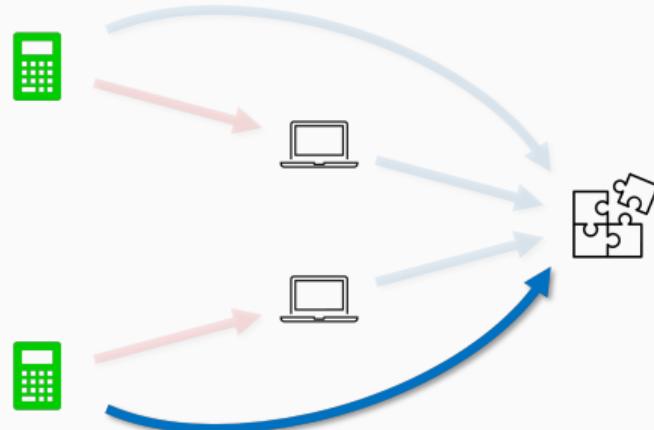


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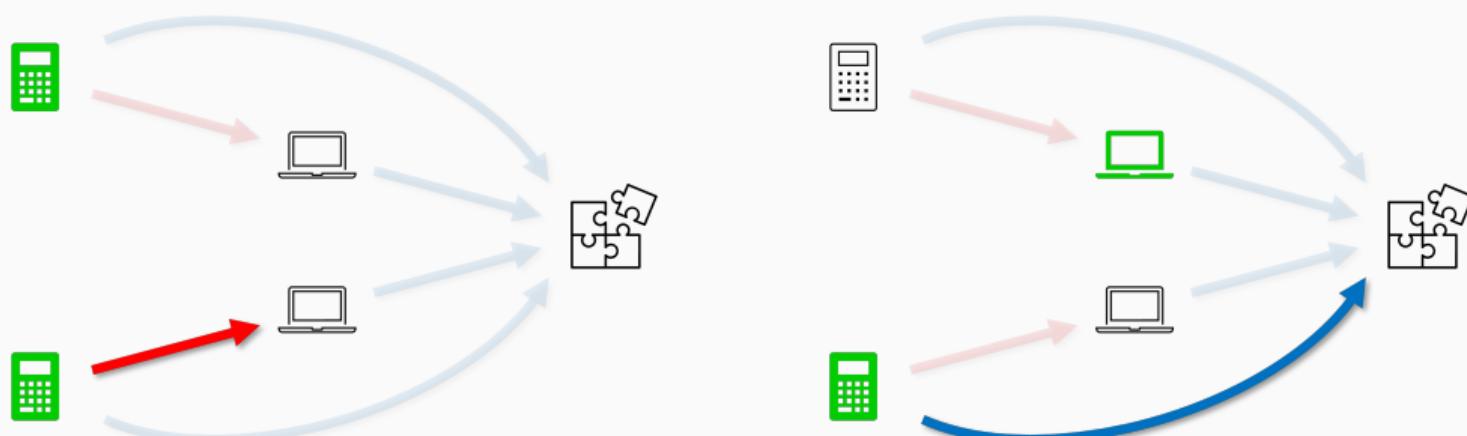


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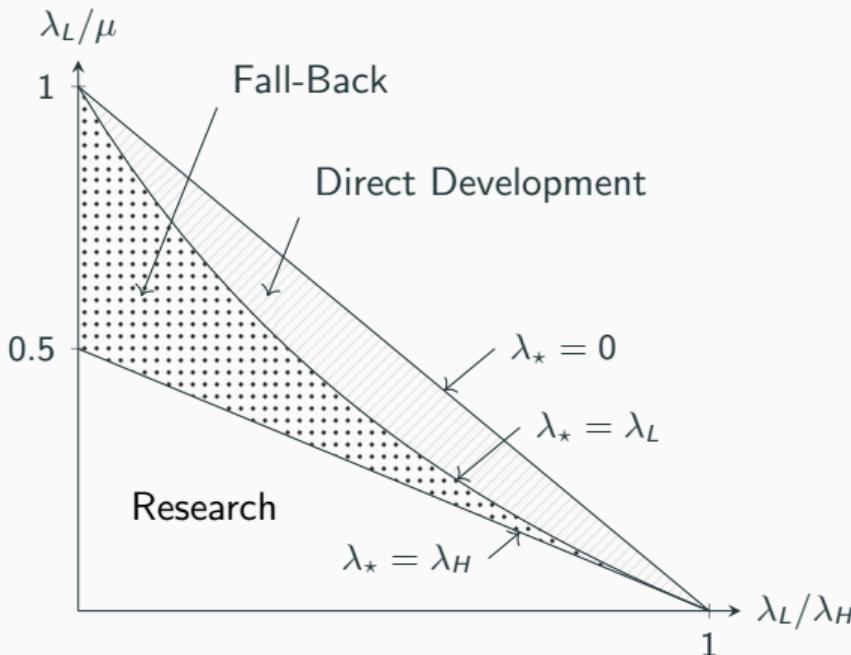
Benchmark Strategy 3: Fall-Back Strategy

Fall-Back Strategy

1. Do research if the rival does not possess the new technology;
2. Switch to developing with the old technology once the rival discovers



Public Information: MPE Characterization



Theorem 1

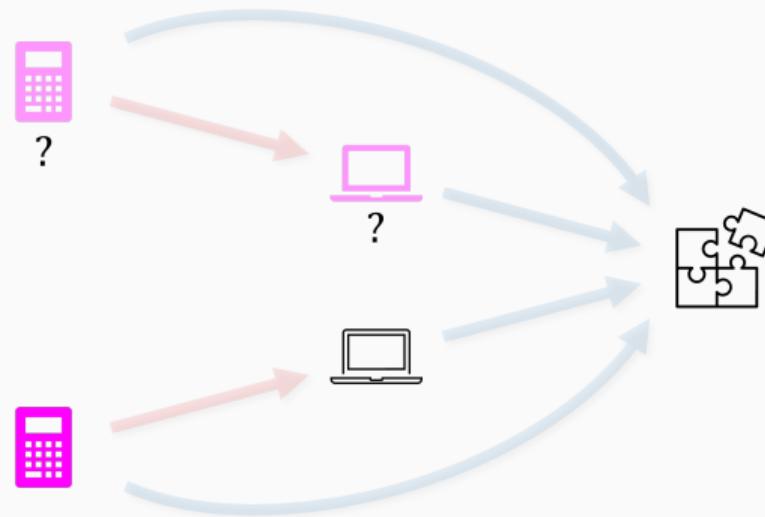
Suppose that firms' research status is public info. The *unique* MPE is characterized as follows:

1. If $\lambda^* > \lambda_H$, both firms play the research strategy;
2. If $\lambda_H > \lambda^* > \lambda_L$, both firms play the fall-back strategy;
3. If $\lambda_L > \lambda^*$, both firms play the direct-development strategy.

Private Information Setting

Private Information: Strategies

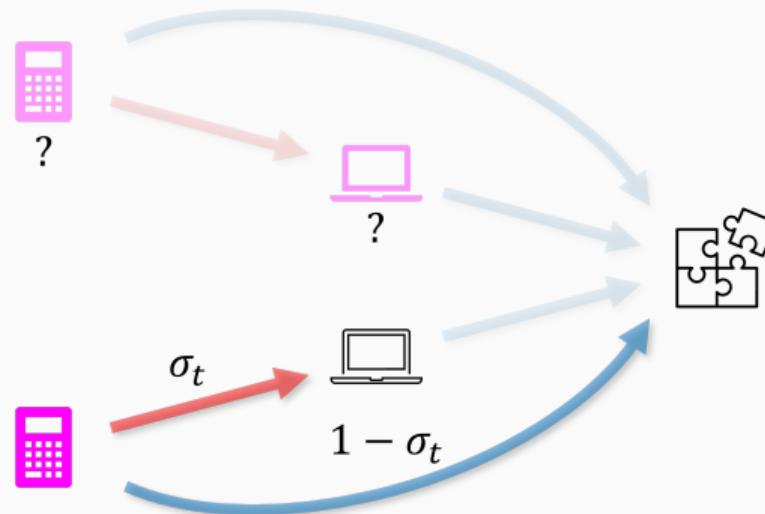
- Firms cannot observe rivals' research progress



Strategy: $\sigma : \mathbb{R}_+ \rightarrow [0, 1]$

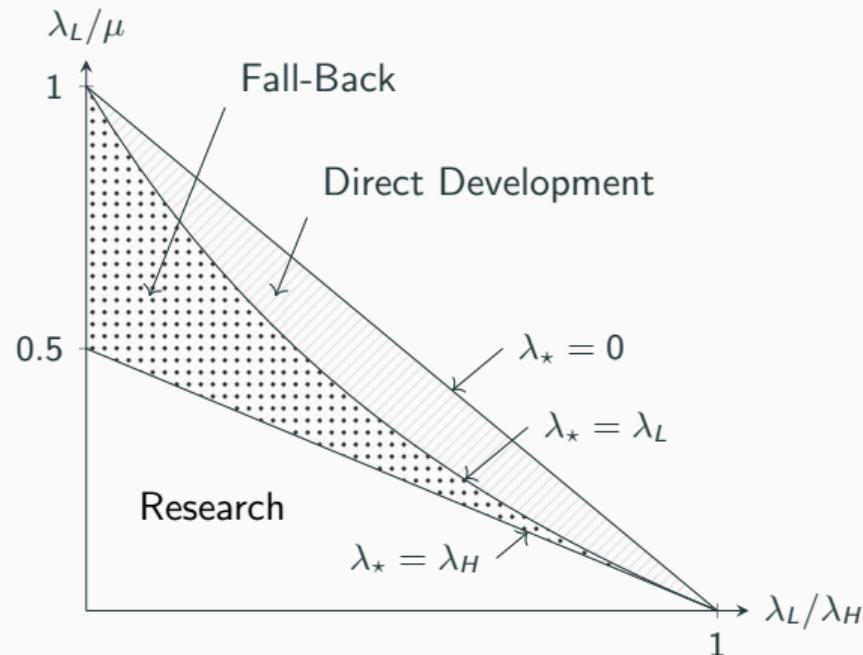
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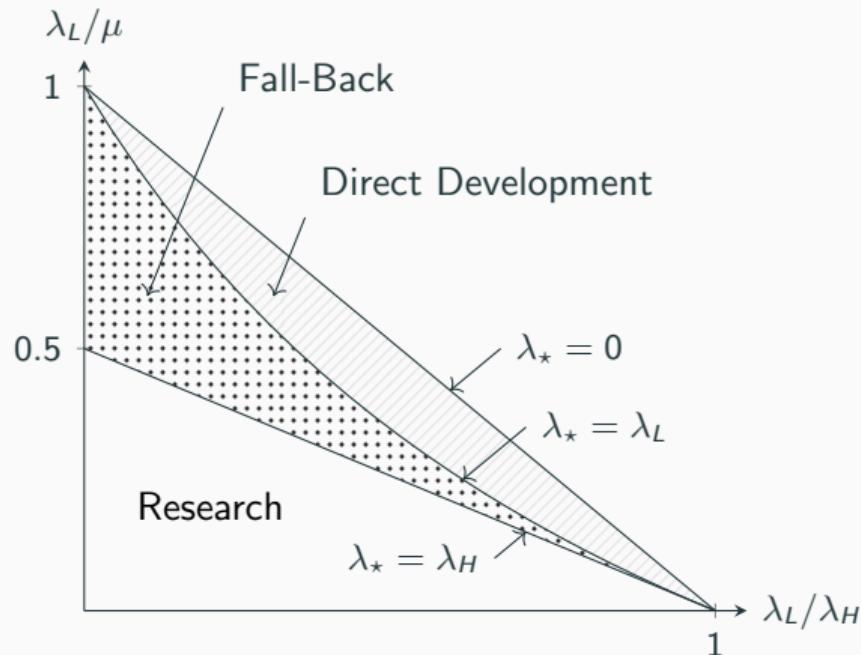
Public Information Results Revisited



Outside of the fall-back region,
firms do not utilize information
about rivals' research status
⇒ Same equilibrium under pri-
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What happens in the fall-back
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Public Information Results Revisited



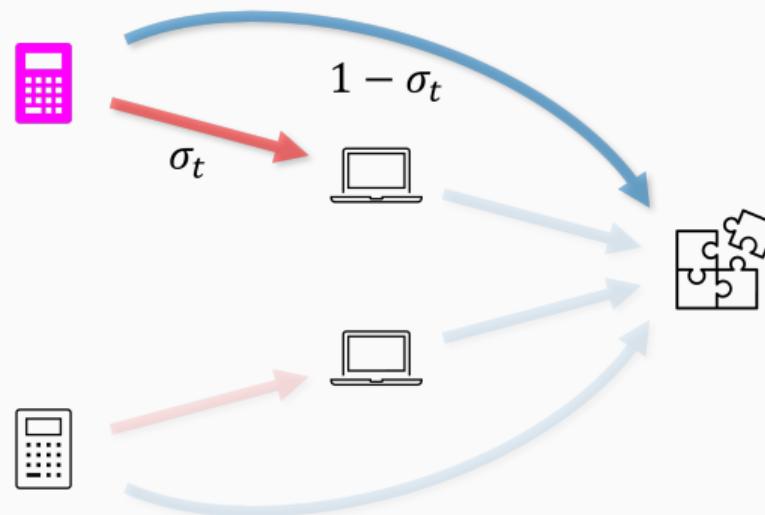
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Private Information: Belief Updating

- Given the rival's strategy σ , the firm forms a belief p

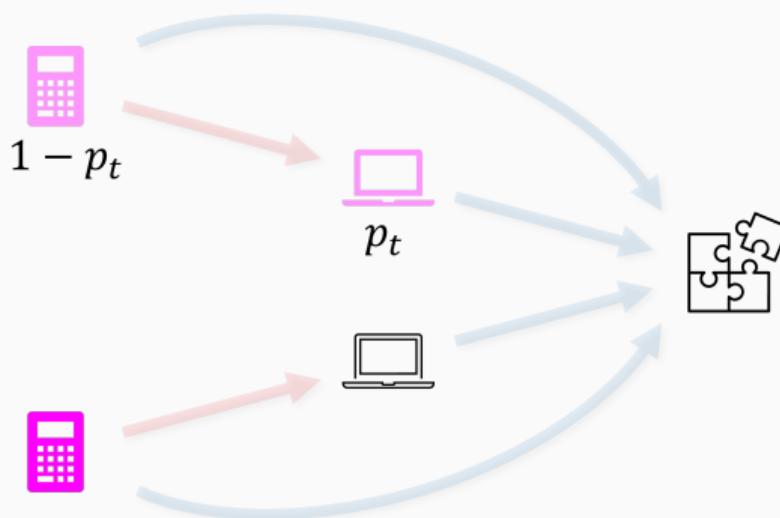
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Private Information: Evolution of Beliefs

- p_t : the probability that Firm i assigns to Firm j having the new technology at time t given no success in product development

Lemma: Evolution of Beliefs

Given Firm j 's strategy σ , p_t is characterized by the initial condition $p_0 = 0$ and

$$\dot{p}_t = \underbrace{\mu \cdot \sigma_t}_{\text{DE}} - \underbrace{[\lambda_H - (1 - \sigma_t)\lambda_L] \cdot p_t}_{\text{SRE}} \cdot (1 - p_t).$$

- **Duration Effect (DE):** As time passes, it is more likely that Firm j has the new technology
- **Still-in-the-Race Effect (SRE):** No product development implies that it is less likely that Firm j has the new technology

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1. if $\lambda_H \leq \mu$, $\lim_{t \rightarrow \infty} p_t = 1$;
2. if $\lambda_H > \mu$, $\lim_{t \rightarrow \infty} p_t = \mu / \lambda_H$,

where μ is the rate of research, and λ_H is the rate of development with the new tech

- When p is high enough, the firm might want to partially switch to developing with the old technology.
- When $\lambda_H > \mu$ and p cannot exceed a certain level, the firm might want to keep conducting research.

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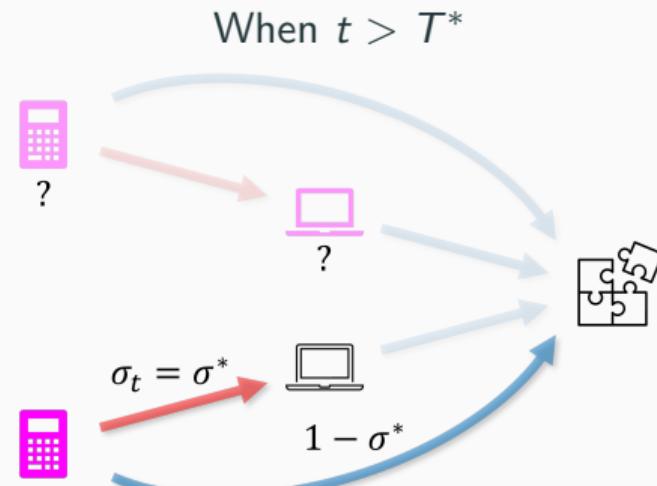
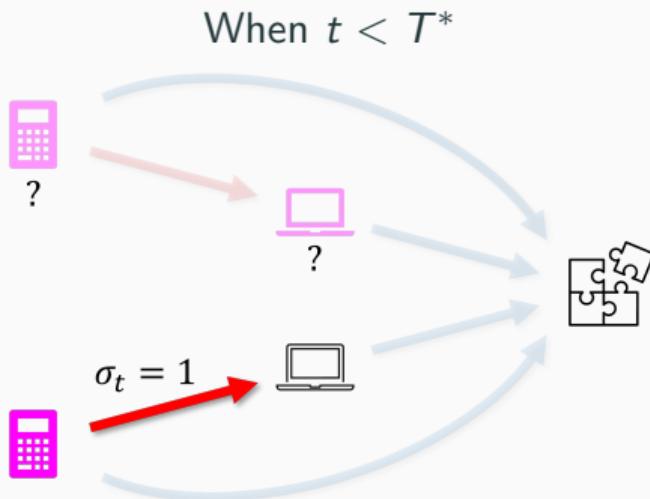
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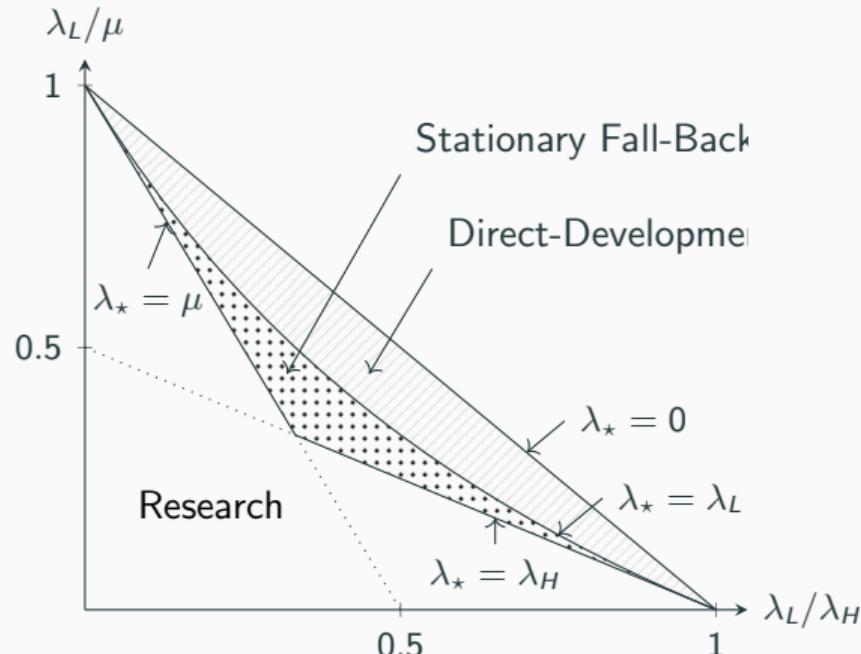
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Private Information: Stationary Fall-Back Strategy



- In addition, $p_t = p^*$ for all $t \geq T^*$

Private Information: Equilibrium Characterization



Theorem 2

When firms' research status is private info, there are three types of equilibria:

- (i) if $\lambda_* > \min\{\lambda_H, \mu\}$, the research equilibrium;
- (ii) if $\lambda_* < \lambda_L$, the direct-dev. equilibrium;
- (iii) if $\lambda_* \in (\lambda_L, \min\{\lambda_H, \mu\})$, the stationary fall-back equilibrium

Patent, License and Trade Secret

Patent, License and Trade Secret

- Extend the model by allowing firms to patent & license the new technology
- Once a firm discovers the new technology, it can either
 1. apply for a patent (details will follow); or
 2. not apply for a patent—protects the new technology via *trade secret*
- Patent vs. Trade Secret
 - Patent applications are publicly available information
 - With trade secret protection, the information about the discovery is not released, but the firm may face a risk of losing the right to use the new technology
 - There is a trade secret protection level $\alpha \in [0, 1]$ (will be described soon)

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Patent, License and Trade Secret

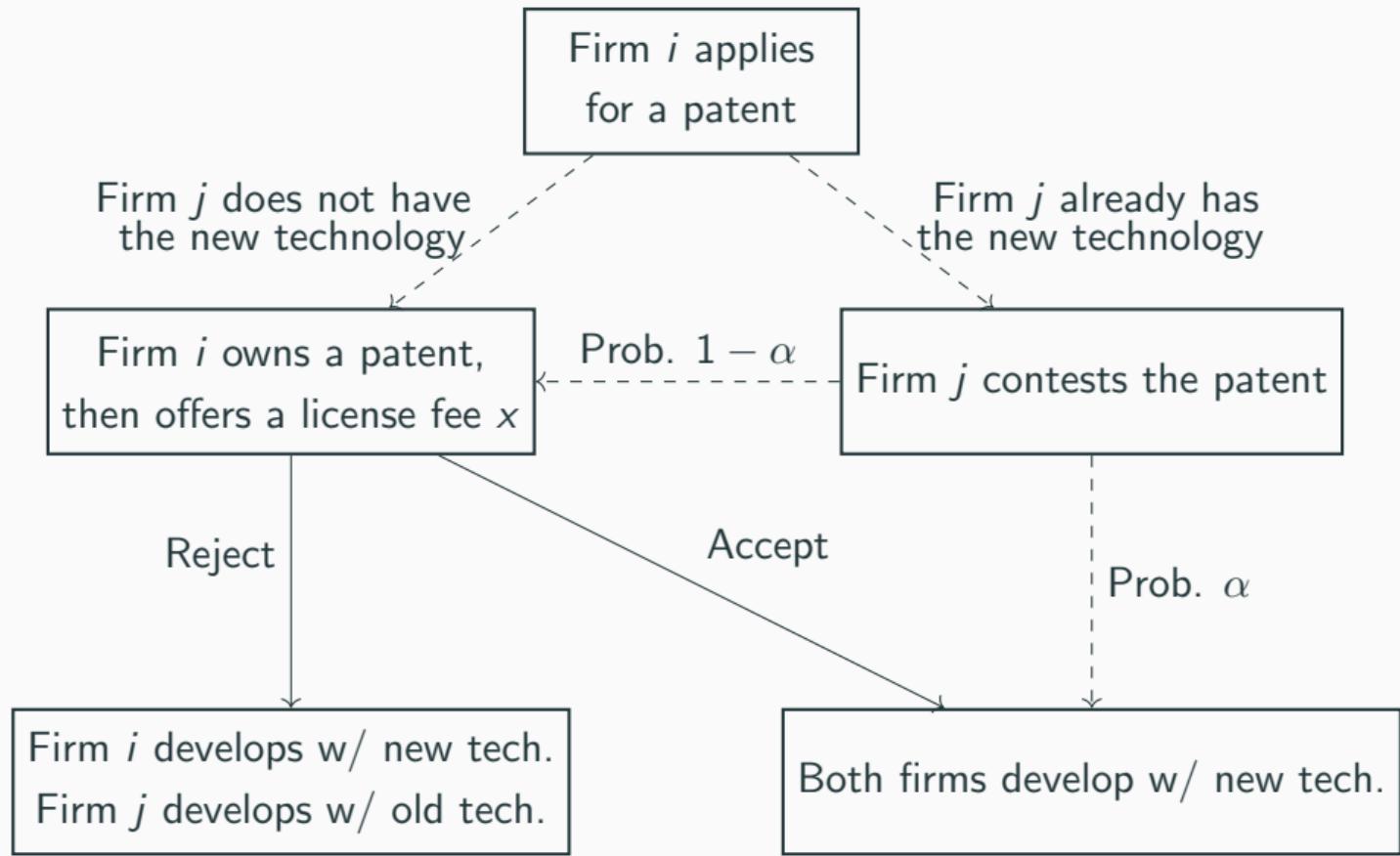
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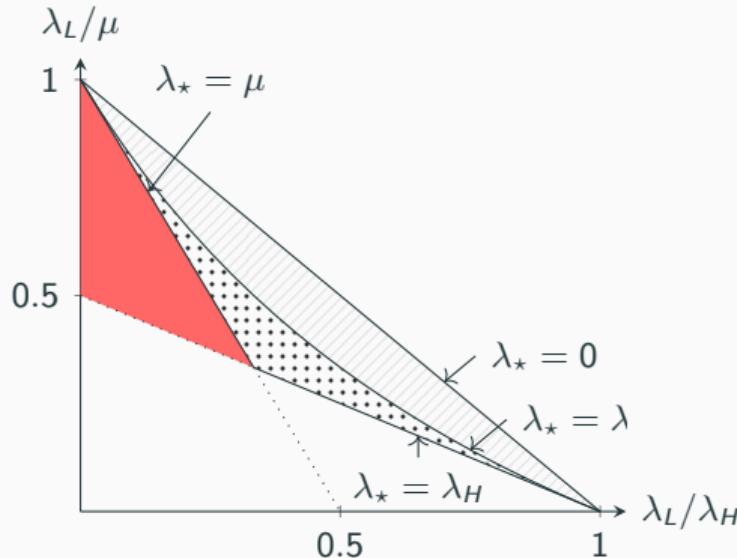
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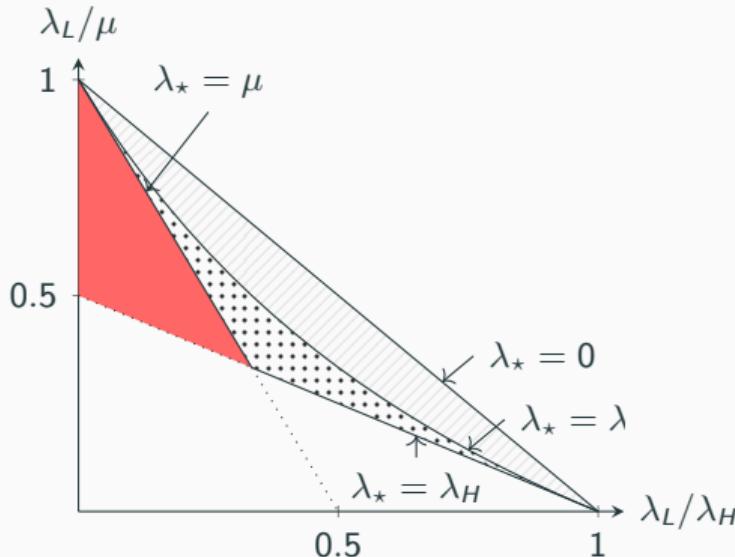


Patent, License and Trade Secret: Equilibrium



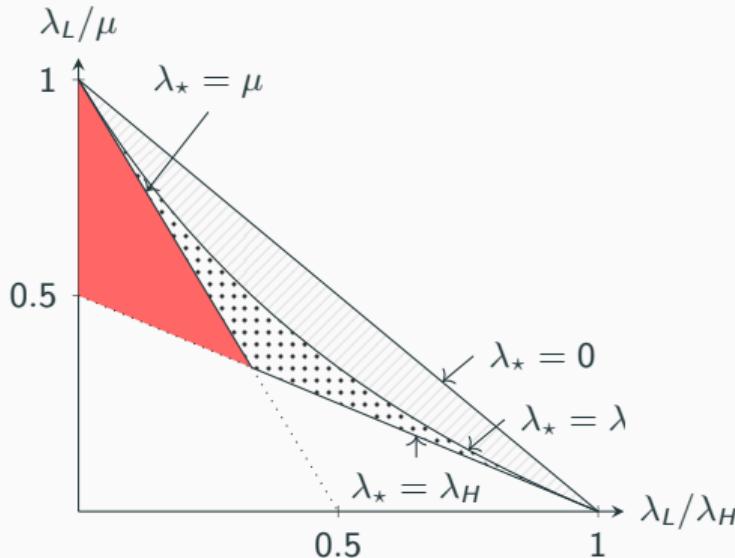
- Focus on $\lambda_H > \lambda_* > \mu$
- Public info: fall-back strategy
- Private info: research strategy
- **Efficient Patent Equilibrium:**
firms conduct research and apply for patents once they discover the new tech.
- **Concealment Equilibrium:**
firms conduct research and do not apply for patents at all

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Theorem 4

There exists $\tilde{\alpha} > \hat{\alpha}$ and $\tilde{\Pi} : (\tilde{\alpha}, 1] \rightarrow \mathbb{R}_+$ such that $\tilde{\Pi}(\alpha) > \hat{\Pi}(\alpha)$ and the concealment equilibrium exists if and only if $\alpha > \tilde{\alpha}$ and $\Pi > \tilde{\Pi}(\alpha)$.

- Why does Π matter?
 - Patent \rightarrow information revealed \rightarrow rival's outside option changes
 \rightarrow license fee is determined given that the rival is developing w/ old tech.
 - When Π is high, a firm may want the rival *squander* its time in research

Patent, License and Trade Secret: Equilibrium

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There exists $\tilde{\alpha} > \hat{\alpha}$ and $\tilde{\Pi} : (\tilde{\alpha}, 1] \rightarrow \mathbb{R}_+$ such that $\tilde{\Pi}(\alpha) > \hat{\Pi}(\alpha)$ and the concealment equilibrium exists if and only if $\alpha > \tilde{\alpha}$ and $\Pi > \tilde{\Pi}(\alpha)$.

- Why does Π matter?
 - Patent \rightarrow information revealed \rightarrow rival's outside option changes
 \rightarrow license fee is determined given that the rival is developing w/ old tech.
 - When Π is high, a firm may want the rival *squander* its time in research

Patent, License and Trade Secret: Equilibrium

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Patent, License and Trade Secret: Takeaways

- Firms' patenting decisions crucially depend on the reward of winning the race (Π) and the trade secret protection level (α)
 - When α is low or Π is *small*, the new technology is patented and licensed
(Outcome is equivalent to the **First-Best** case)
 - When α is high and Π is *high*, firms conceal their discoveries
(Outcome is equivalent to the **Private Information** case)
- Implications
 - The first-best outcome can be achieved by lowering either Π or α
(e.g., imposing tax in the innovative product market; shifting the patent system from 'first-to-invent' to 'first-to-file')
 - Caveat: too low Π may induce the firms to exit the race

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Related Literature and Conclusion

Literature on Patent vs. Secrecy

- **Empirical Studies**
 - Many surveys indicate that companies regard secrecy as more effective than patents
(Hall, Helmers, Rogers, Sena '14)
▶ Surveys
- **Theoretical Literature:** Structural Limitations of Patent
 - Filing a patent is costly
 - Patent protection is limited (e.g., Denicolo, Franzoni '04)
 - Patent can be infringed (e.g., Anton, Yao '04)
- **This paper:** Strategic Advantage of Secrecy
 - By concealing research progress, firms can hinder their rivals from adjusting R&D strategies

▶ Related Literature

Conclusion

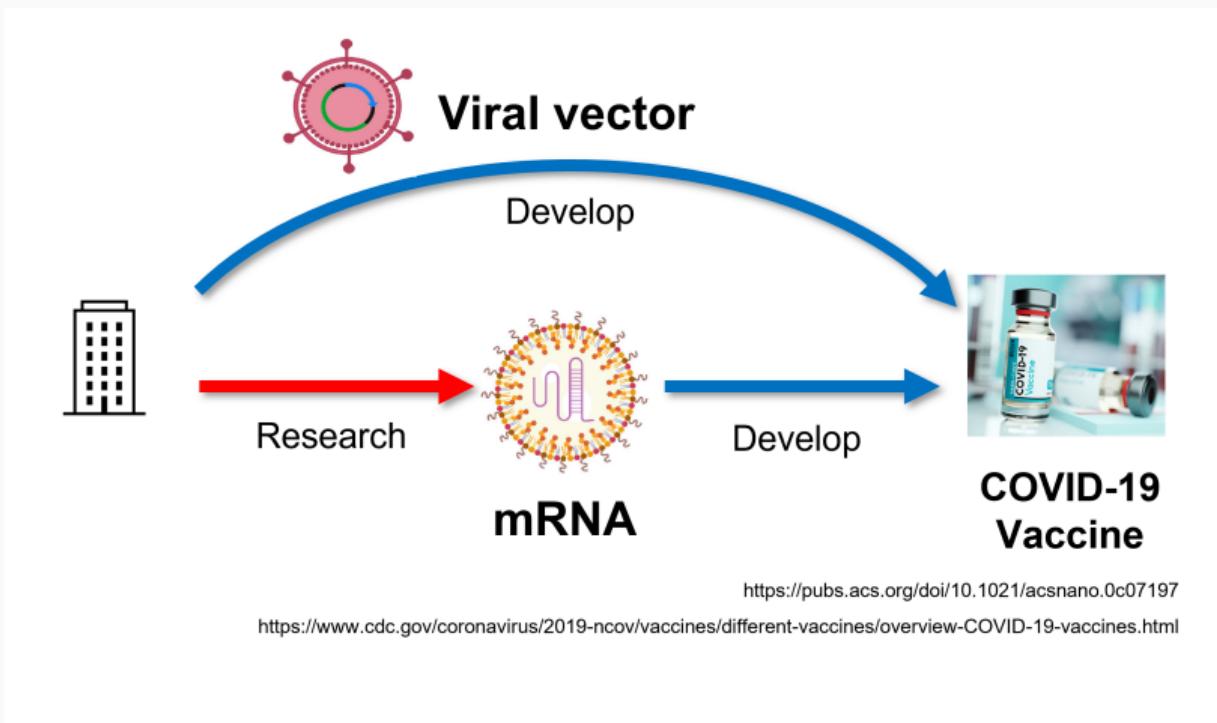
- We study firms' strategic incentives to conceal their interim technology
 - We introduce an innovation race model with multiple paths
 - We characterize the equilibrium behaviors of firms when their research progress is public or private information
 - We study firms' patenting behavior: Under a strong trade secret protection, Prize of winning the race $\uparrow \Rightarrow$ Incentives to conceal $\uparrow \Rightarrow$ Socially inefficient

Conclusion

- We study firms' strategic incentives to conceal their interim technology
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Thank you!

Preview of Framework: Further Examples



Preview of Framework: Further Examples

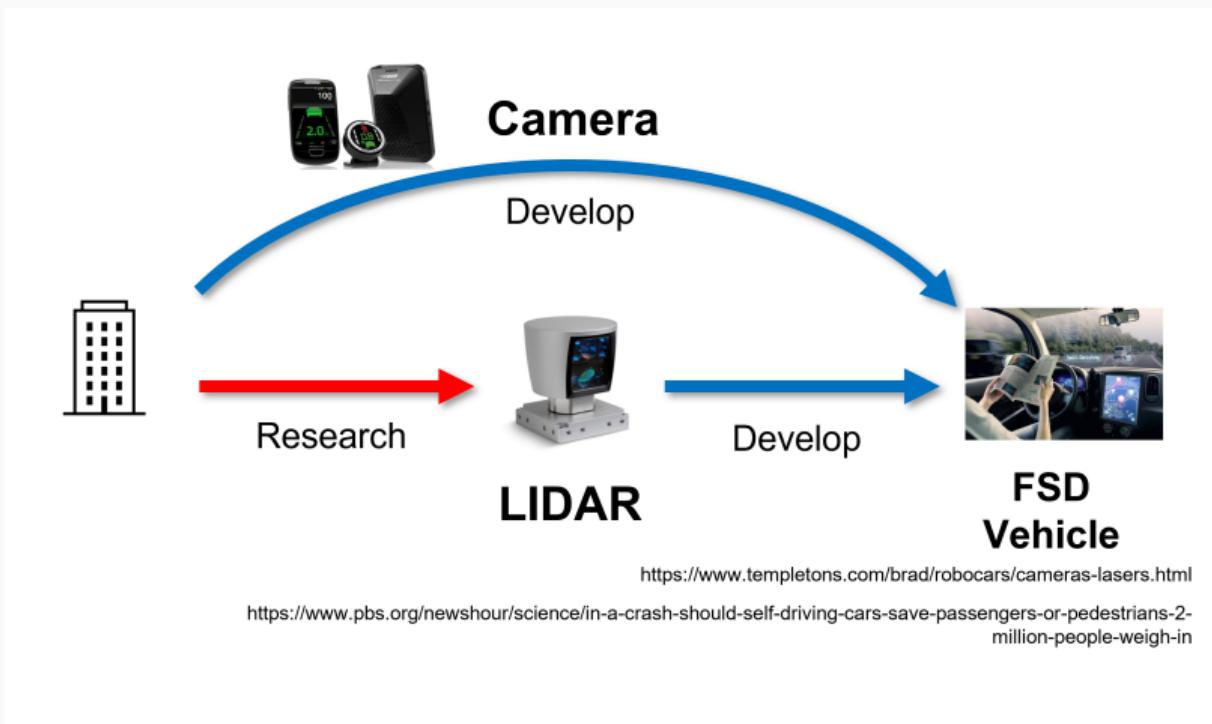


TABLE 3
SUMMARY OF MAIN SURVEY RESULTS

| Survey | Levin et al. (1987) | Brouwer and Kleinknecht (1999) | Arundel (2001) | Cohen et al. (2000) | Blind et al. (2006) | Arundel et al. (1995); Arundel and Kabla (1998) | Cohen et al. (2002) |
|-----------------|---|----------------------------------|---|----------------------------------|---|---|--|
| Period covered | 1981–1983 | 1990–1992 | 1990–1992 | 1994 | 2002 | 1990–1992 | 1994 |
| Country | U.S. | NL | DE, LU, NL, BE, DK, IE, NO | U.S. | DE | UK, DE, IT, NL, BE, ES, DK, FR | U.S., JP |
| Coverage | 650 lines of business, R&D-doing mfg. publicly traded firms | 1,000–2,000 mfg. firms | 2,849 R&D doing mfg. firms | 1,165 large R&D-doing mfg. firms | 522 firms with ≥ 3 EPO patent applications | 414 PACE + 190 French large R&D-doing mfg. firms | 593 large R&D-doing mfg. firms |
| High importance | Patents | Prod.: 4.3* Proc.: 3.5* | Prod.: 25% Proc.: 18% | Prod.: 11% Proc.: 7% | Prod.: 35% Proc.: 23% | 79% Prod.: 67% Proc.: 46% | Prod.: JP 38%; US 36% Proc.: JP 25%, US 24% |
| | Secrecy | Prod.: 3.6* Proc.: 4.3* | Prod.: 33% Proc.: 41% | Prod.: 17% Proc.: 20% | Prod.: 51% Proc.: 51% | 58% Prod.: 54% Proc.: 65% | Prod.: JP 26%; US 51% Proc.: JP 29%, US 53% |
| Lead time | Patents | Prod.: 5.4* Proc.: 5.1* | Prod.: 57% Prod.: 56% | Prod.: 54% Prod.: 47% | Prod.: 53% Prod.: 38% | 88% Prod.: 67% Prod.: 46% | Prod.: JP 41%; US 52% Prod.: JP 28%, US 38% |
| | Patents | High: pharma Low: pulp, paper | High: pharma/ chemicals/petroleum Low: basic metals | n.a. | High: medi- cal equipment, pharma Low: printing/ publishing | High: rubber & plastic, biotech Low: construc- tion/mining | High: pharma Low: prod.: utilities; proc.: electrical equip. |

or

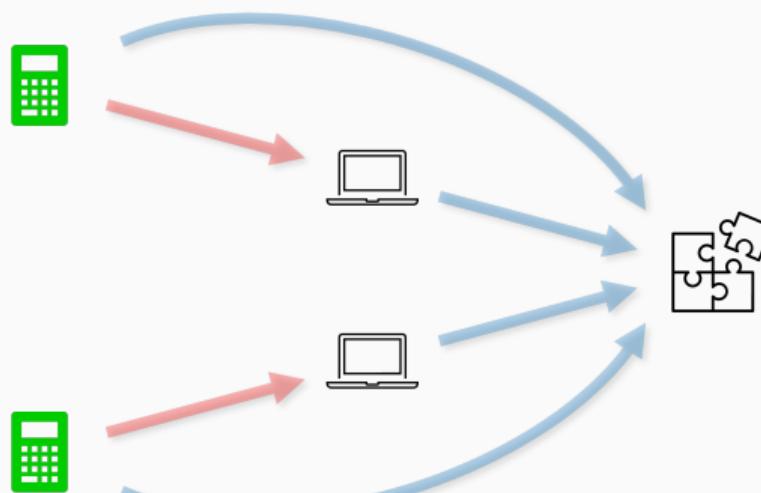
Related Literature

- **Innovation Races:** Loury ('79); Lee, Wilde ('80);
 - **Patent vs. Secrecy:** Horstmann et al. ('85); Denicolo, Franzoni ('04); Anton, Yao ('04); Kultti et al. ('07); Zhang ('12); Kwon ('12)
 - **Multiple avenues to innovate:** Akcigit, Liu ('16); Brian, Lemus ('17); Das, Klein ('20); Hopenhayn, Squintani ('21)
 - **Multiple-stage innovation:** Scotchmer, Green ('90); Denicolo ('00)
 - **Timing of disclosure:** Hopenhayn, Squintani ('16); Bobcheff et al. ('17); Song, Zhao ('21)
- **Interim R&D Knowledge:** Bhattacharya et al. ('86, '92); d'Aspremont et al. ('00); Bhattacharya, Guriev ('06); Spiegel ('07)
- **Hail-Mary Attempts:** Carnehl, Schneider ('22); Kim ('22)

First-Best Problem

- Planner can control the resource allocations and observe research progress
- Planner's goal is to *max* joint profit $\Leftrightarrow \min$ expected completion time
- **First-Best Case:** firms do research and the new technology is immediately shared

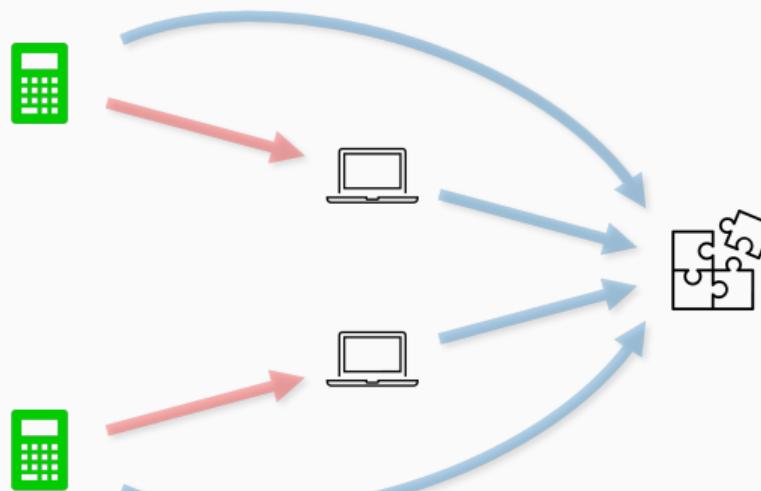
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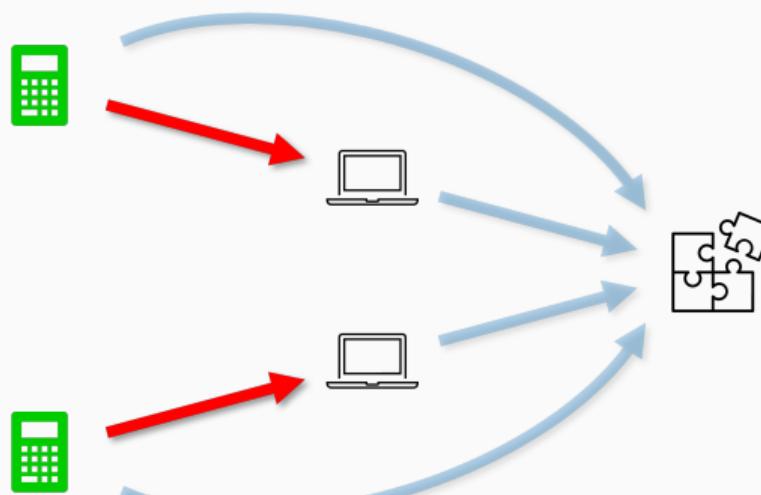
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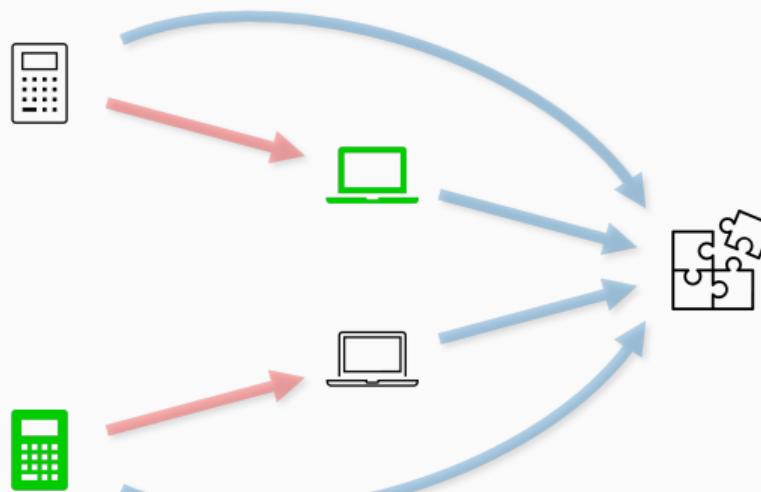
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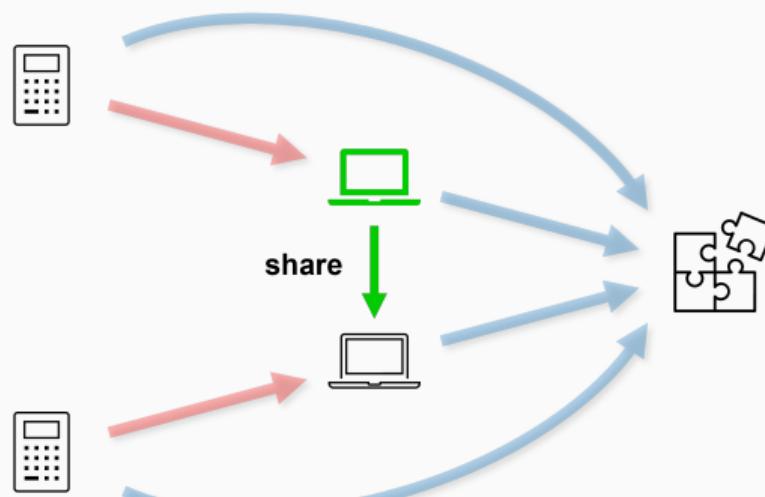
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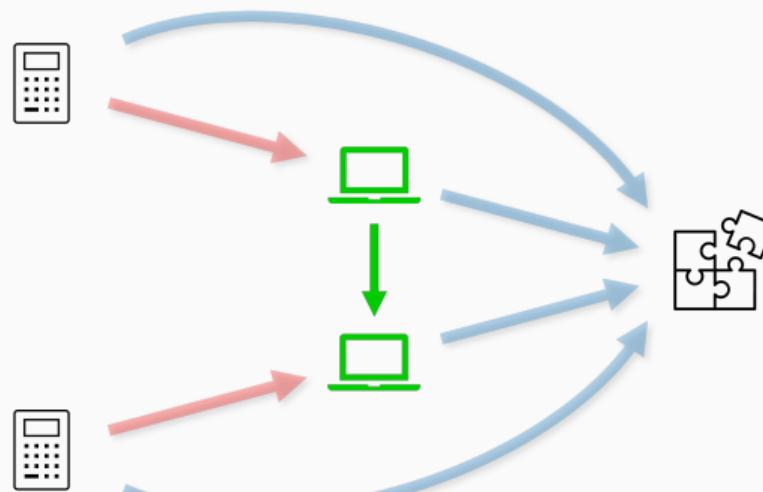
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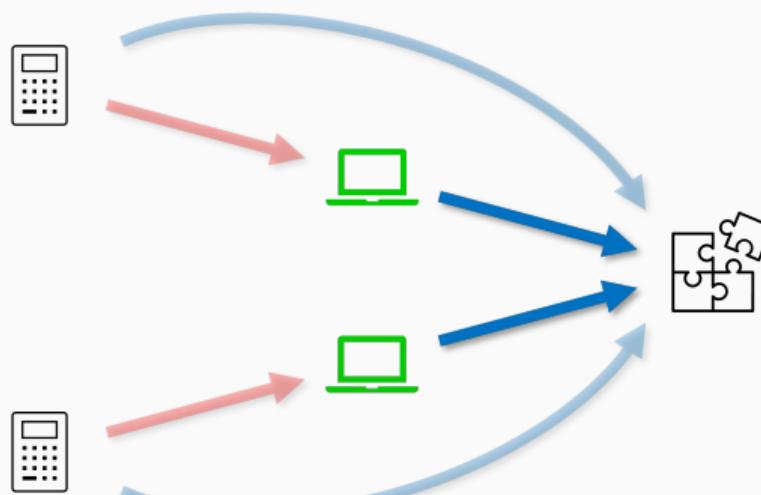
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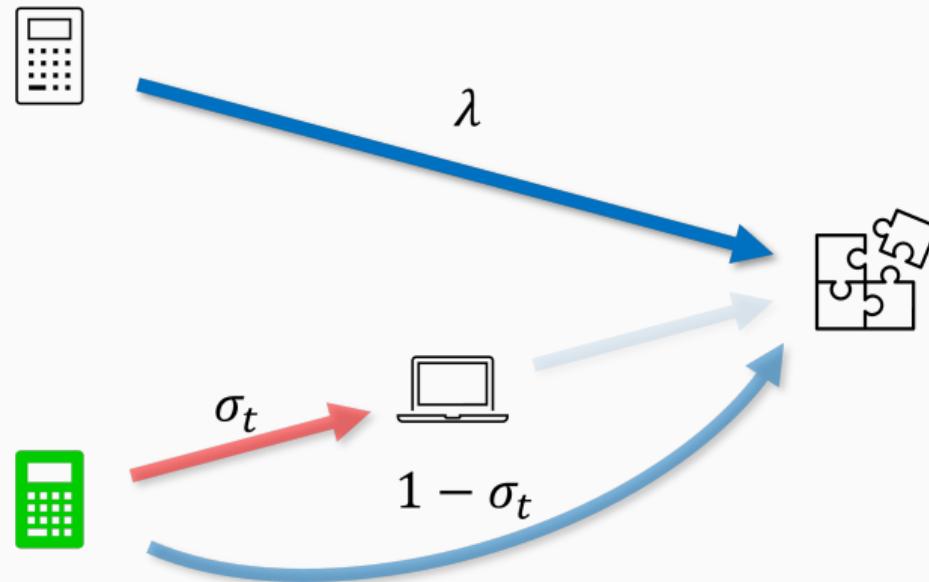
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Benchmark: Constant Development Rate



Low-Reward Cases

- If $\Pi < \frac{c}{\lambda_L}$, the old technology will not be utilized at all.
- There are three subcases:
 1. $\Pi < \left(\frac{1}{\lambda_H} + \frac{1}{\mu}\right) c$:
 - Firms do not engage in innovation in the first place.
 2. $\left(\frac{1}{\lambda_H} + \frac{1}{\mu}\right) c \leq \Pi < \min \left\{ \frac{c}{\lambda_L}, \left(\frac{1}{\lambda_H} + \frac{2}{\mu}\right) c \right\}$:
 - If a firm finds out that the rival has the new technology, it exits the race.
 - Thus, firms as soon as they discover the new technology to expel the rival.
 3. $\left(\frac{1}{\lambda_H} + \frac{2}{\mu}\right) c \leq \Pi < \frac{c}{\lambda_L}$:
 - A firm keeps doing research even if the rival has the new technology.
 - Knowing this, firms would license the new technology as soon as they have.

Formal Definitions of Strategies

- **States:** the set of firms with the new technology

$$\Omega \equiv \{\emptyset, \{A\}, \{B\}, \{A, B\}\}$$

- **Markov Strategy**

$$\sigma_i : \Omega \rightarrow [0, 1]$$

- Once a firm discovers the new technology, the firm's strategy is degenerate:

$$\sigma_i(\{i\}) = \sigma_i(\{i, j\}) = 0$$

- **Benchmark Strategies**

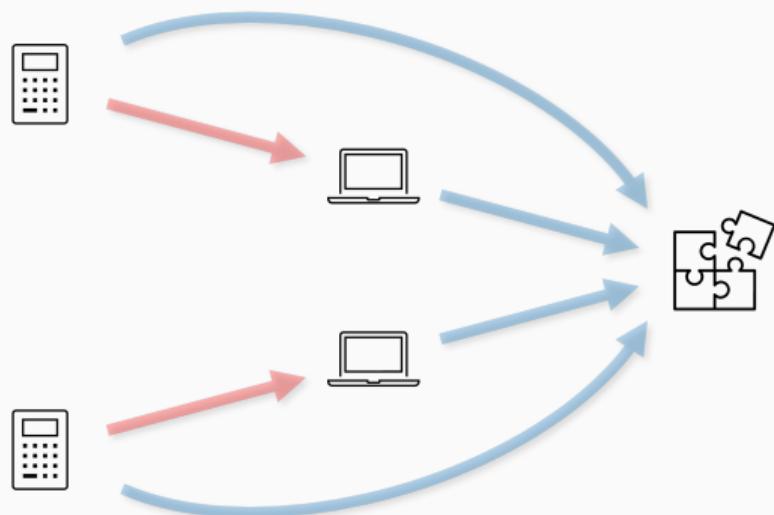
- *Research strategy* : $\sigma_i(\emptyset) = \sigma_i(\{j\}) = 1.$
- *Direct-Development strategy* : $\sigma_i(\emptyset) = \sigma_i(\{j\}) = 0.$
- *Fall-back strategy* : $\sigma_i(\emptyset) = 1$ and $\sigma_i(\{j\}) = 0.$

Patent, License, Trade Secret: Additional Assumptions

- Firms cannot fraudulently claim the possessions of the new technology
- Patent process is instantly completed and free of cost
- Patent never expires

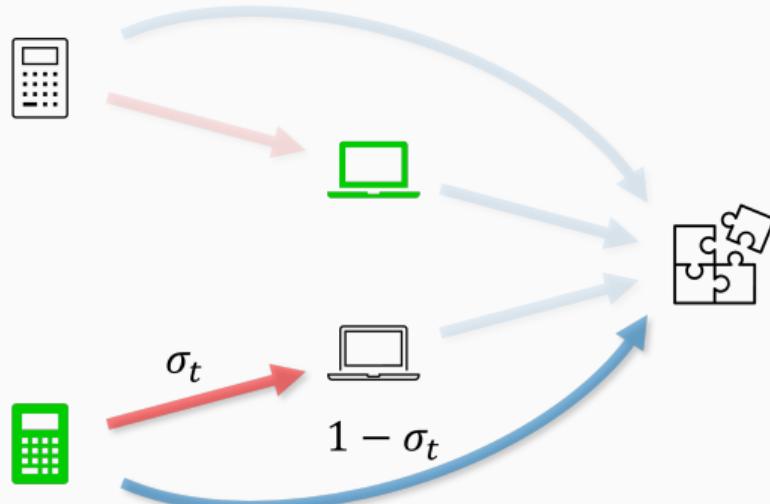
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Preview of Settings and Results



- There are two firms in the race
- The first firm developing the innovative product receives Π and the other firm does not
- Three different settings

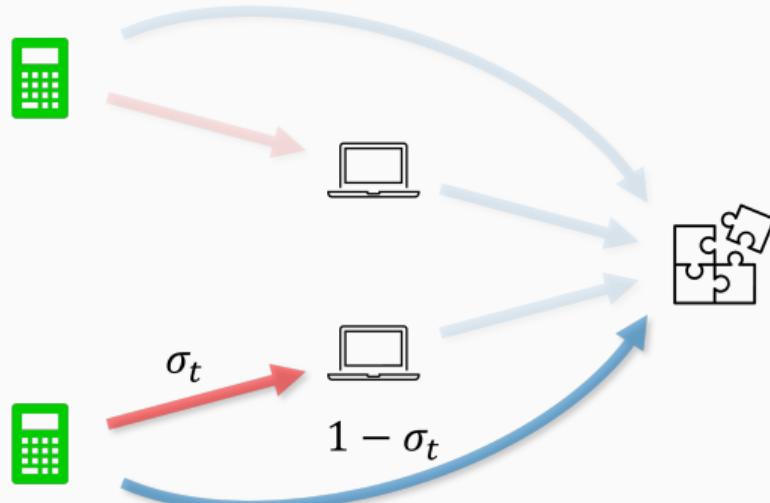
Preview of Settings and Results



1. Public Information Setting

- Firms can observe each others' research progress
- How would firms allocate their resources to research and development over time?
- **Theorem 1:** a firm may switch to develop with the old technology once the rival discovers the new technology

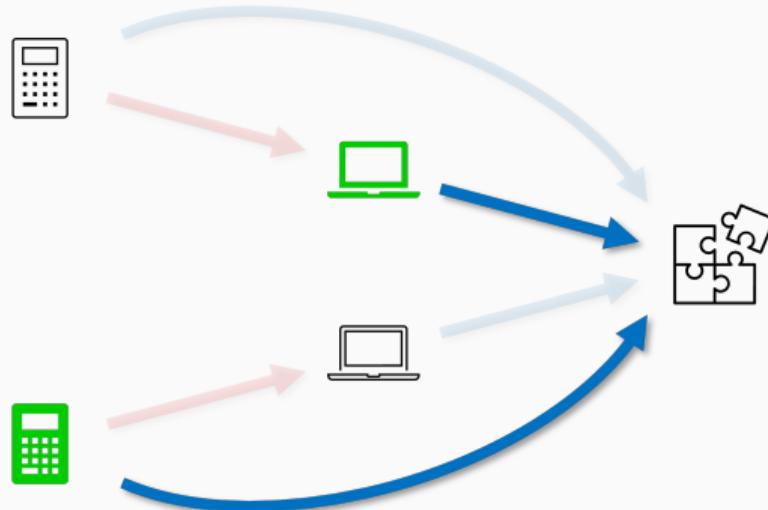
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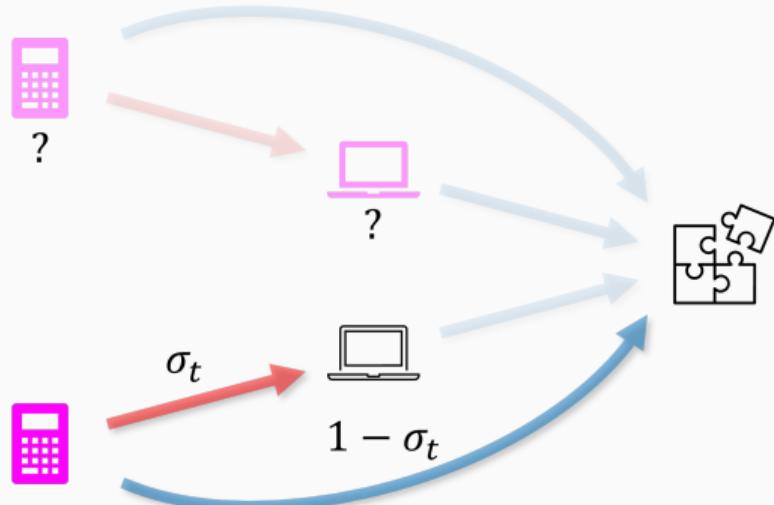
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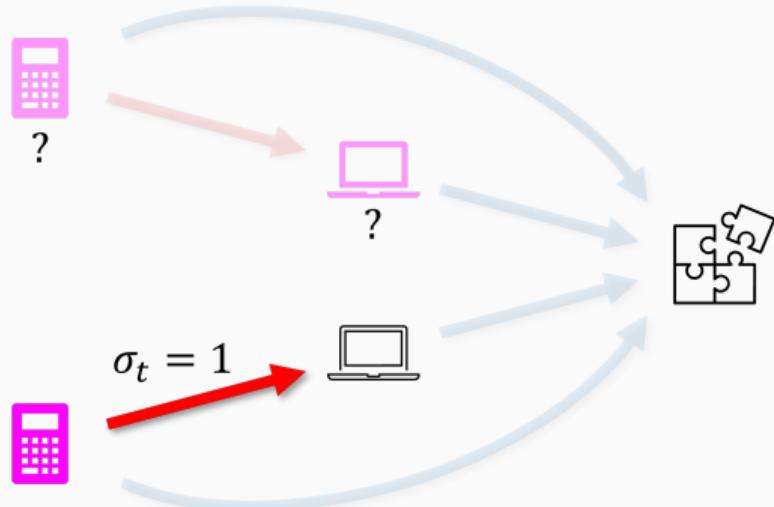


2. Private Information Setting

- Firms cannot observe each others' research progress
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- **Theorem 2:** $\exists T \in [0, \infty]$ and $\sigma_* \in [0, 1]$ s.th.

$$\sigma_t = \begin{cases} 1, & \text{if } t < T, \\ \sigma_*, & \text{if } t > T. \end{cases}$$

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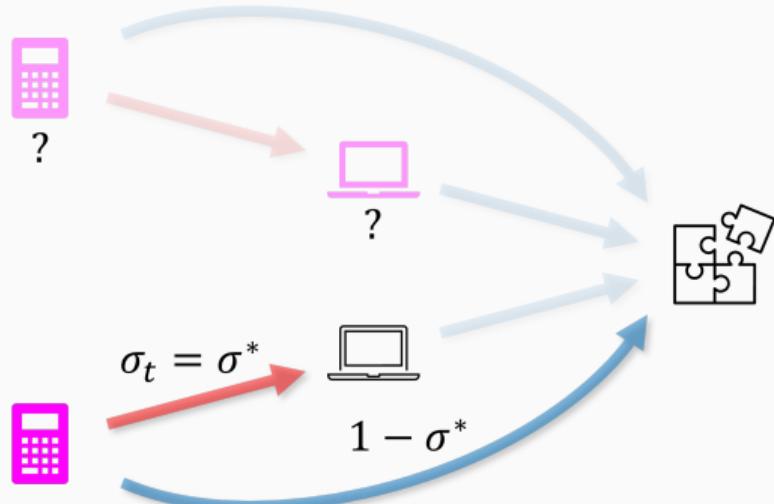


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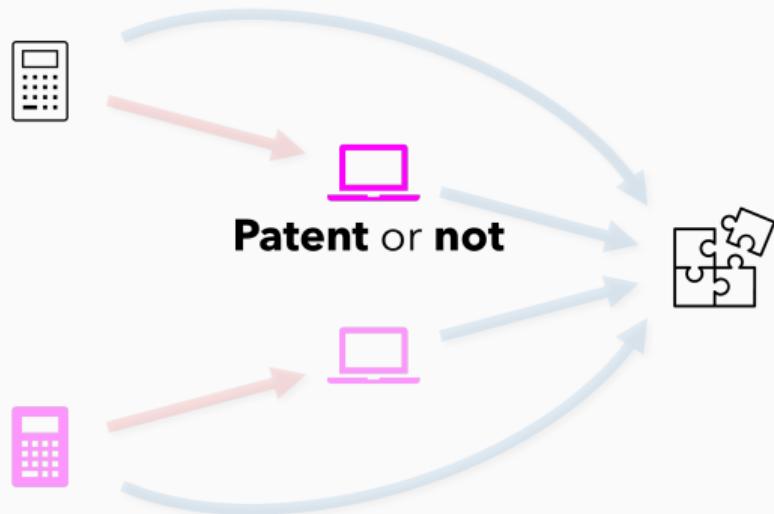


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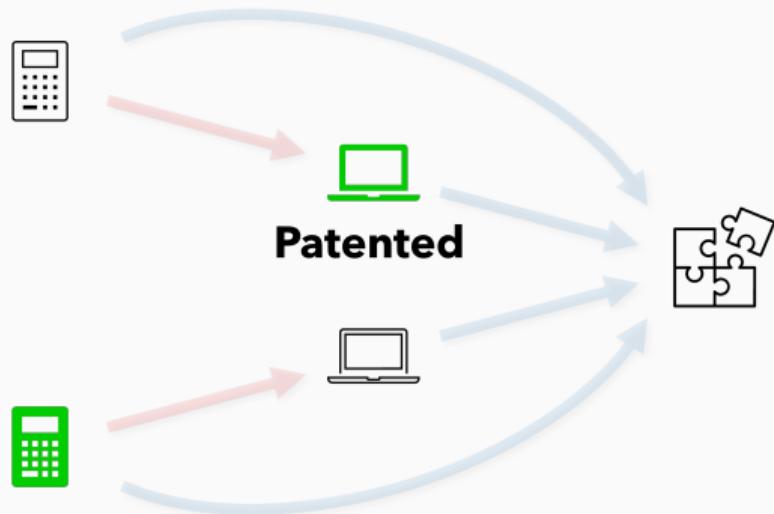
Preview of Settings and Results



3. Patent Game

- Extend the model by allowing firms to choose whether to apply for a patent or not (protect by trade secret)
- Once patented, the firm offers a license offer to the rival firm

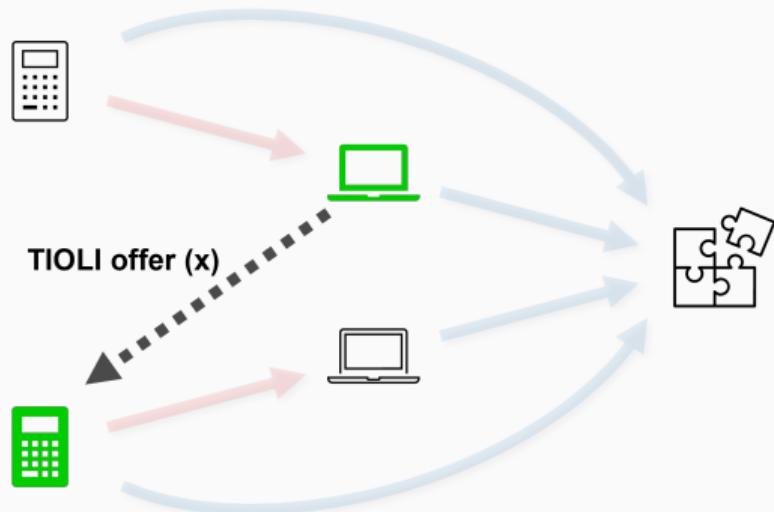
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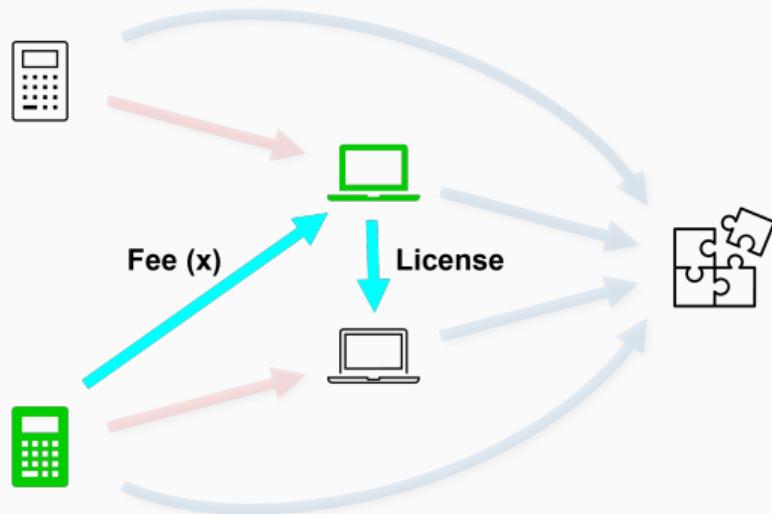
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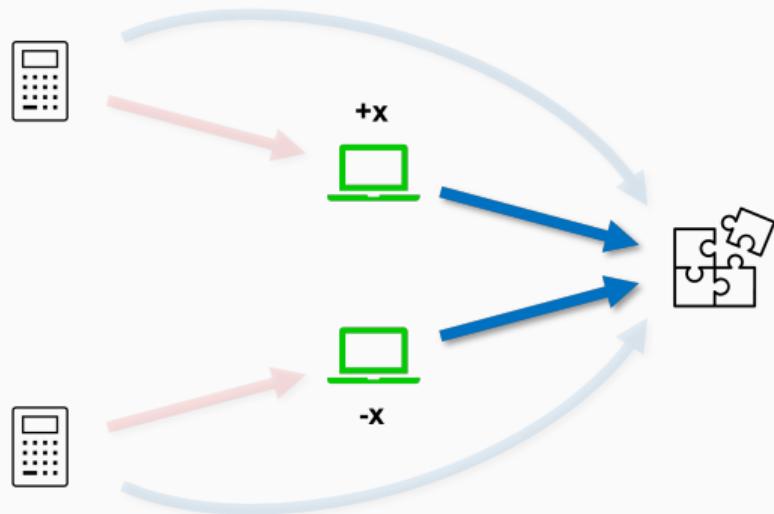
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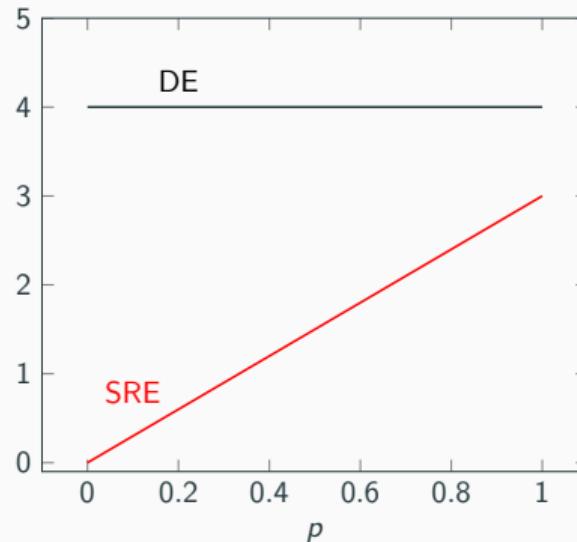
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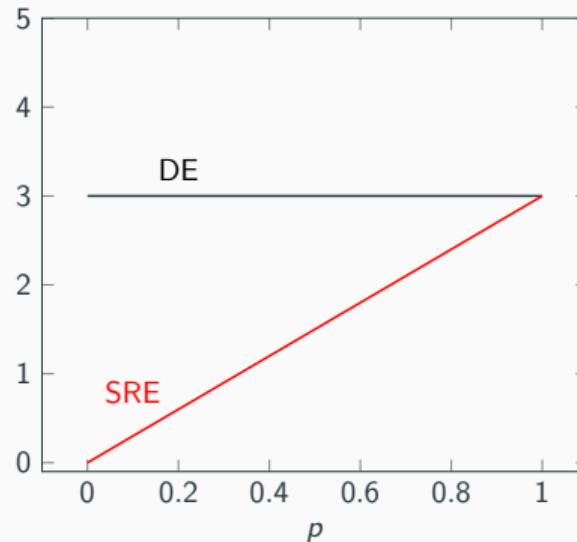
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Private Information: Evolution of Beliefs



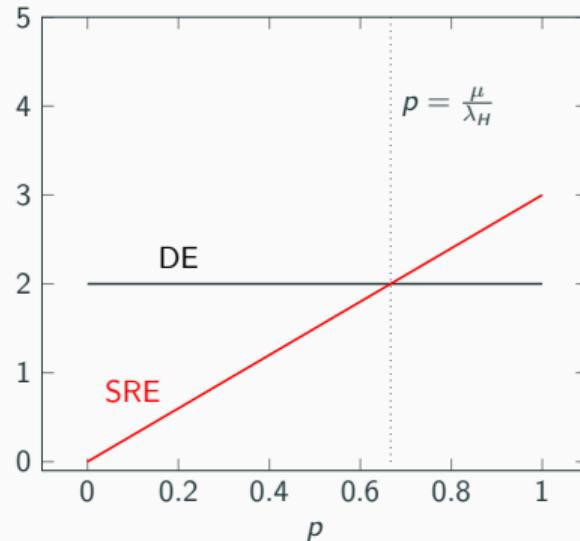
Duration Effect (Black) and Still-in-the-Race Effect (Red)
for $\sigma^j = 1$, $\lambda_L = 1$, $\mu = 4 > \lambda_H = 3$

Private Information: Evolution of Beliefs



Duration Effect (Black) and Still-in-the-Race Effect (Red)
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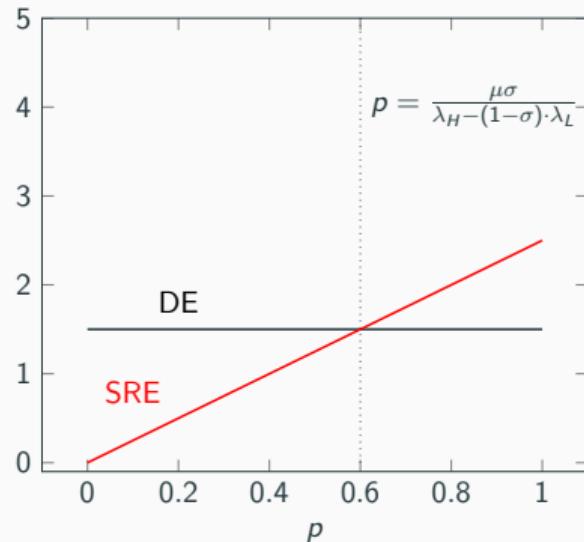
Private Information: Evolution of Beliefs



Duration Effect (Black) and Still-in-the-Race Effect (Red)
for $\sigma^j = 1$, $\lambda_L = 1$, $\mu = 2 < \lambda_H = 3$

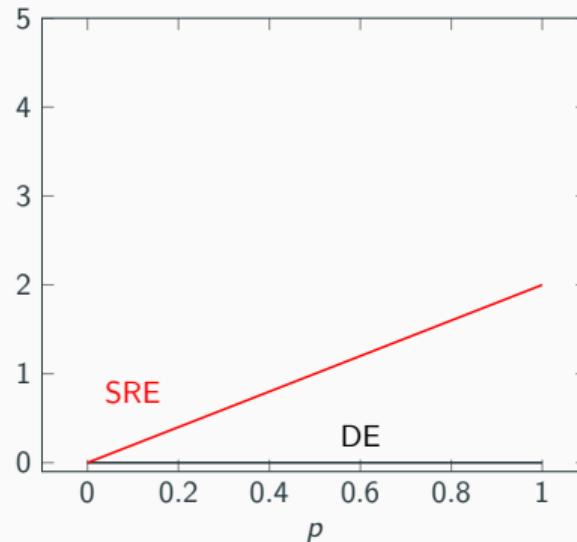
Lemma: when $\mu < \lambda_H$, the belief p cannot exceed μ/λ_H

Private Information: Evolution of Beliefs



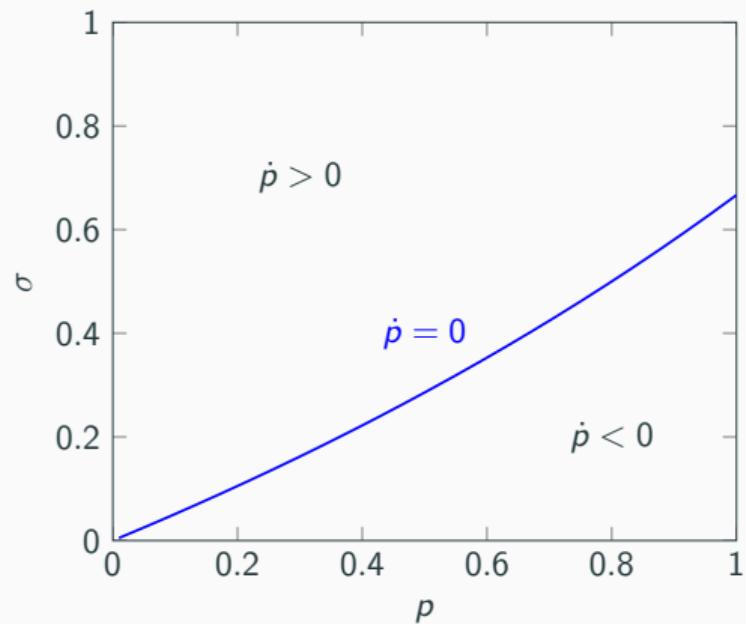
Duration Effect (Black) and Still-in-the-Race Effect (Red)
for $\sigma^j = .5$, $\lambda_L = 1$, $\mu = \lambda_H = 3$

Private Information: Evolution of Beliefs

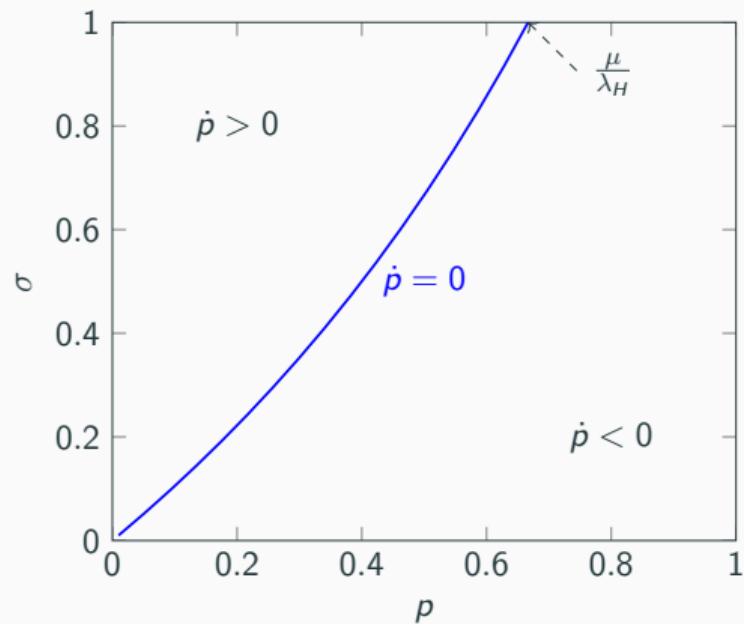


Duration Effect (Black) and Still-in-the-Race Effect (Red)
for $\sigma^j = 0$, $\lambda_L = 1$, $\mu = \lambda_H = 3$

Private Information: Evolution of Beliefs



(a) $\mu > \lambda_H$



(b) $\mu < \lambda_H$

Private Information: Equilibrium Concept

- p_t^σ : prob. that a firm has discovered the new tech. by time t when it employs σ
- h_t^σ : the associated development rate

$$h_t^\sigma = p_t^\sigma \cdot \lambda_H + (1 - p_t^\sigma) \cdot (1 - \sigma_t) \cdot \lambda_L \quad (2)$$

- σ exhibits the *monotone development rate* (MDR) property if h^σ is weakly increasing in t
- **Solution concept:** Nash Equilibrium with Monotone Development Rate (MDNE)
 - (σ^A, σ^B) is a Nash equilibrium
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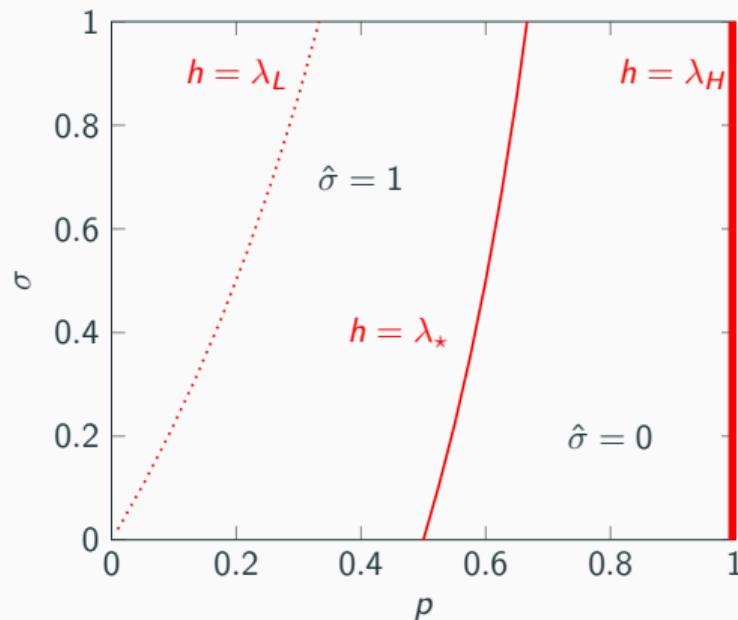
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Private Information: Iso-development-rate Curve and Best Responses

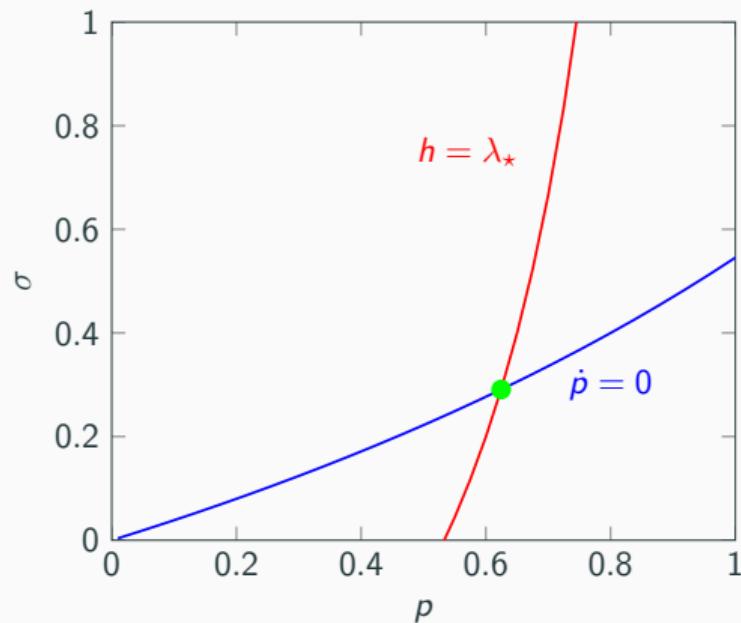


Iso-development curve and the best response when $\lambda_\star \in (\lambda_L, \lambda_H)$

$\hat{\sigma}$ is the best response
 $h(p, \sigma) \equiv p\lambda_H + (1 - p)(1 - \sigma)\lambda_L$

▶ Proposition 1

Private Information: Steady State

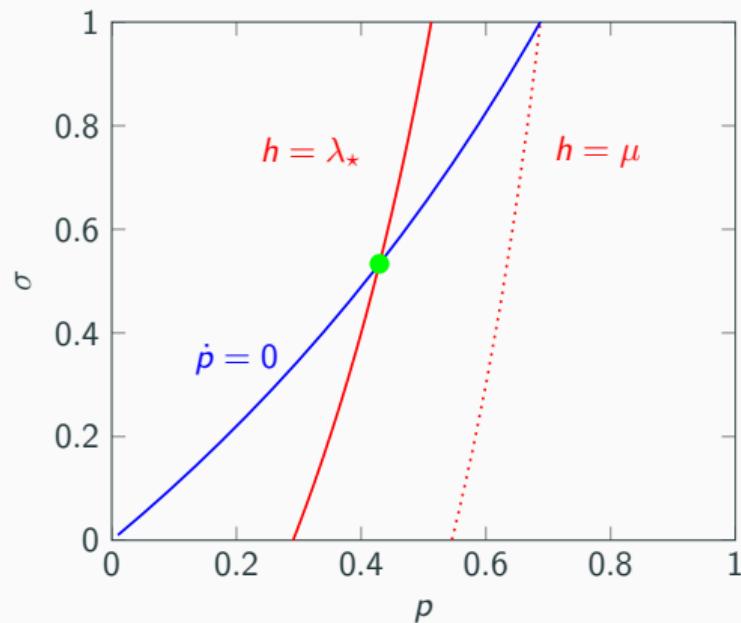


A pair (p_*, σ_*) is called the *steady state* if $\dot{p} = 0$ and $h = \lambda_*$

Lemma: the steady state exists iff
 $\lambda_* \in (\lambda_L, \min\{\mu, \lambda_H\})$

$$\mu > \lambda_H \text{ and } \lambda_H > \lambda_* > \lambda_L$$

Private Information: Steady State

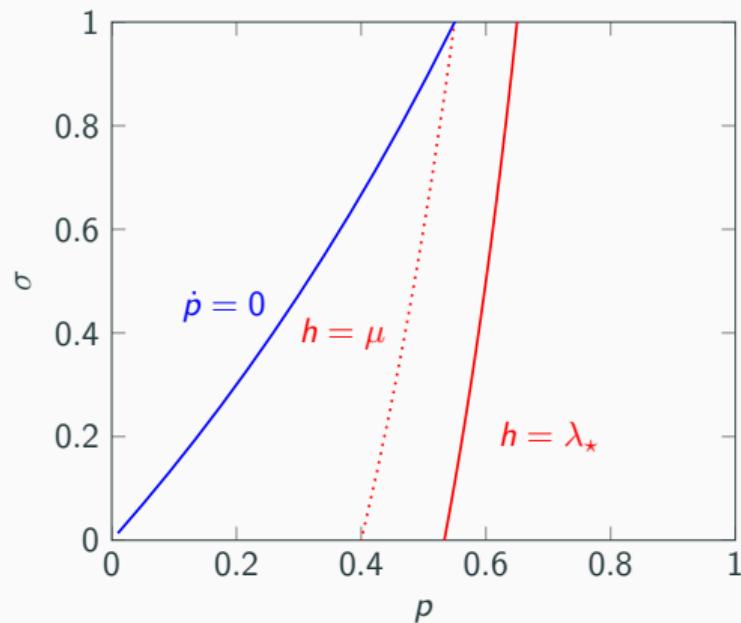


$$\lambda_H > \mu \text{ and } \mu > \lambda_* > \lambda_L$$

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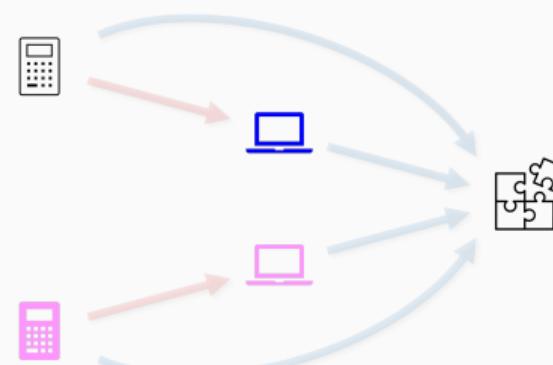
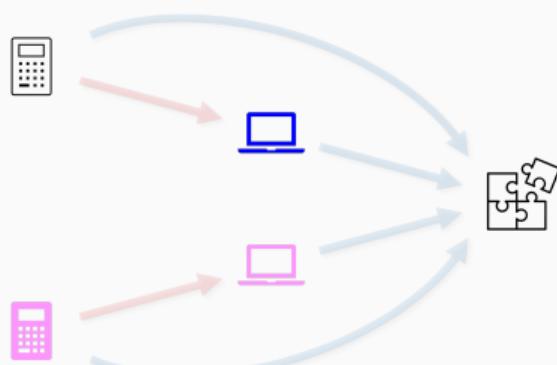
$$\lambda_H > \mu \text{ and } \lambda_* > \mu$$

A pair (p_*, σ_*) is called the *steady state* if $\dot{p} = 0$ and $h = \lambda_*$

Lemma: the steady state exists iff
 $\lambda_* \in (\lambda_L, \min\{\mu, \lambda_H\})$

Patent, License and Trade Secret

- When a firm applies for a patent, it discloses the discovery of the new tech.
- This gives the exclusive right to use the new technology unless the rival's contest is successful
- The patenting firm makes a TIOLI license offer



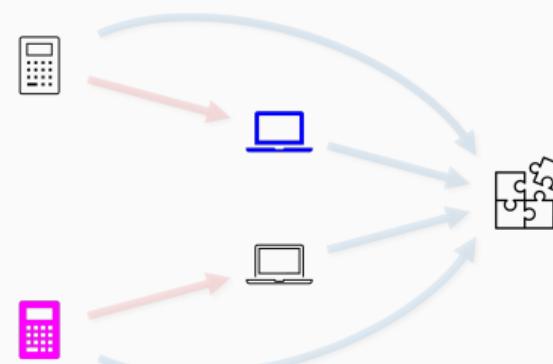
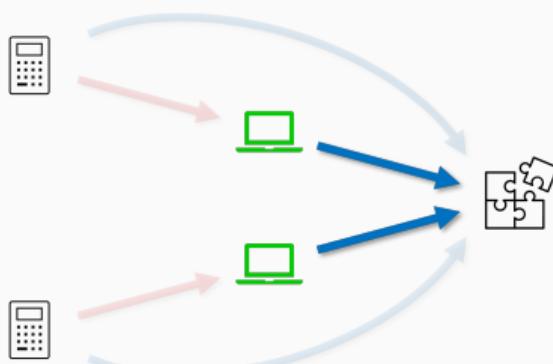
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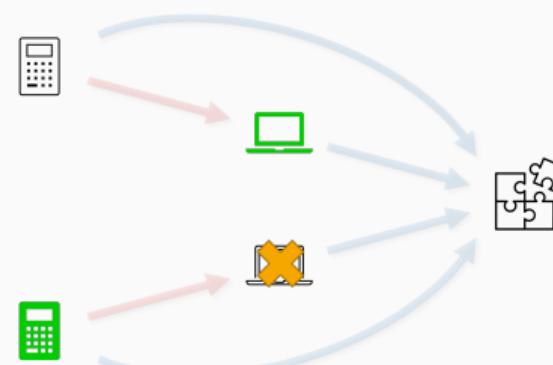
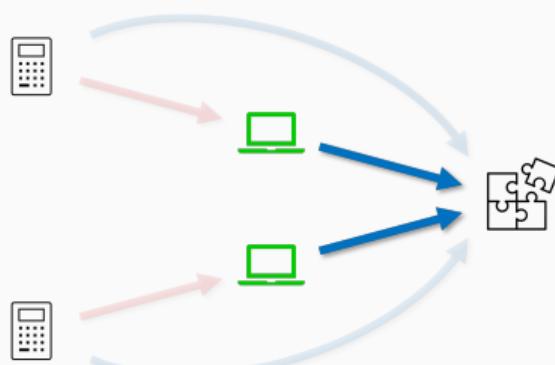
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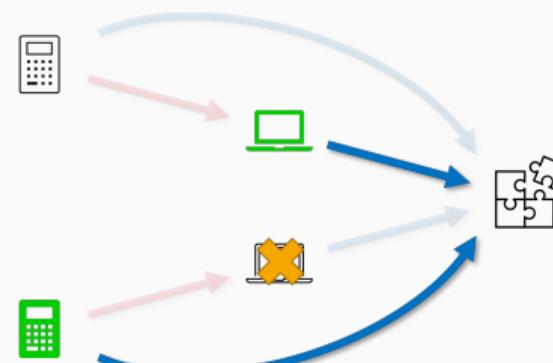
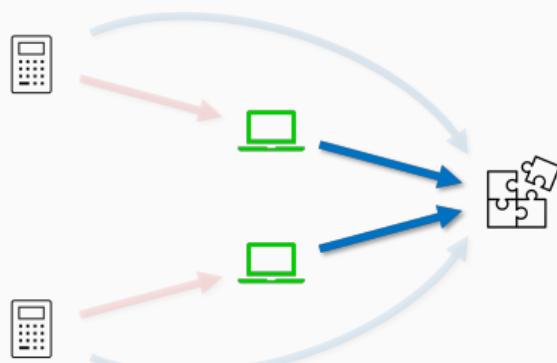
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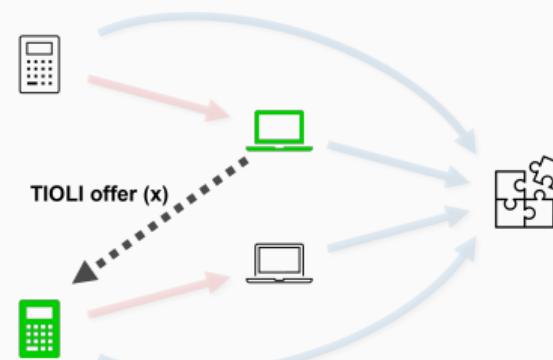
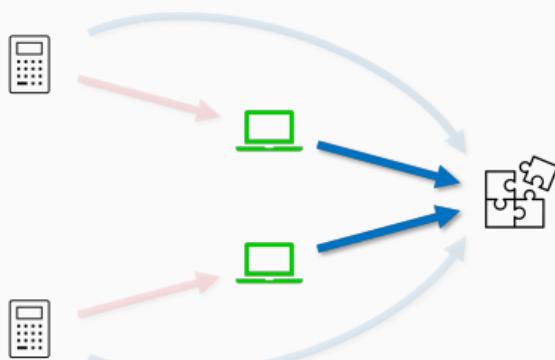
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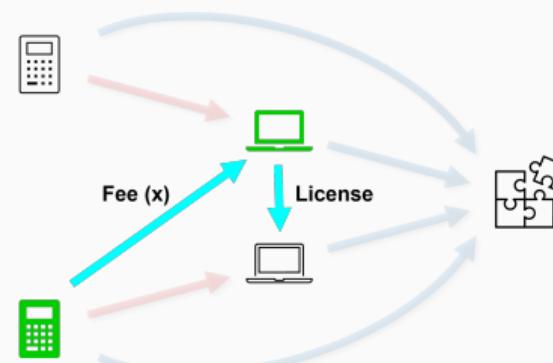
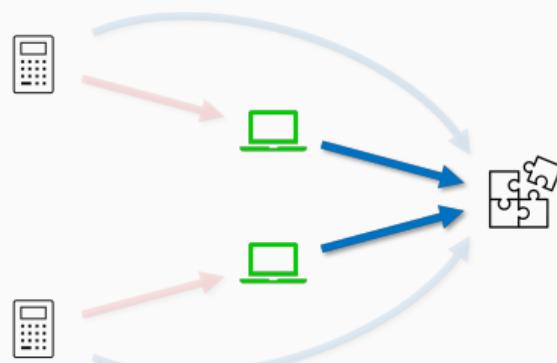
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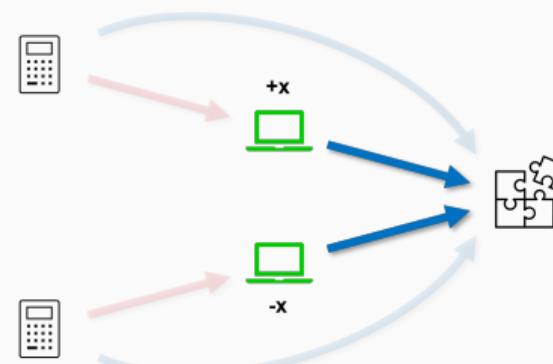
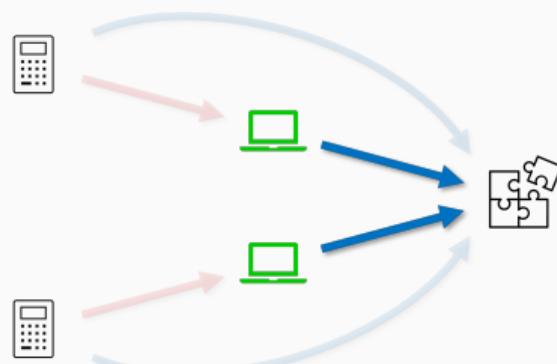
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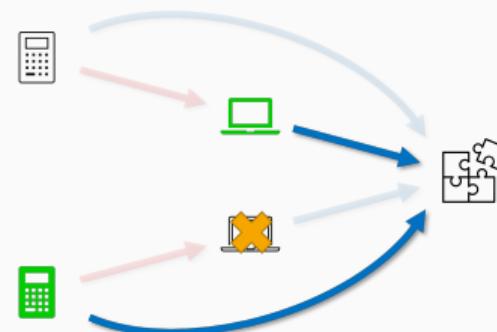
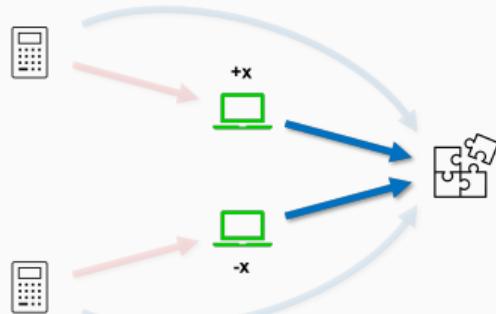


Patent, License and Trade Secret: Optimal License Fee

Proposition

Suppose that a firm has obtained the patent for the new technology. Then, the firm offers the following license fee:

$$x^* \equiv \frac{\lambda_H - \lambda_L}{\lambda_H + \lambda_L} \cdot \frac{\lambda_H \Pi + c}{2\lambda_H}$$



Patent, License and Trade Secret: Optimal License Fee

Observation

- $V_C = \frac{\lambda_H \Pi - c}{2\lambda_H}$: each firm's expected payoff when they race with the new tech.
- $\frac{x^*}{V_C} = \frac{\lambda_H - \lambda_L}{\lambda_H + \lambda_L} \cdot \frac{\lambda_H \Pi + c}{\lambda_H \Pi - c}$ is decreasing in Π
- **Intuition:** the license fee is related to the savings of cost

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