Strategic Concealment in Innovation Races

Yonggyun (YG) Kim

Duke University

Francisco Poggi

University of Mannheim

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Introduction

- Multiple firms racing toward developing an innovative product
  - e.g., Software, COVID-19 vaccine, FSD vehicle
- First firm to develop the product will receive the *reward* from winning the race
  - e.g., transitory monopoly profit
- Would the increase of reward speed up the innovation?
  - Yes? Reward ↑ $\Rightarrow$ Competition ↑ $\Rightarrow$ Innovation Speed ↑
  - **This paper:** No
    - due to the strategic concealment of intermediate research findings

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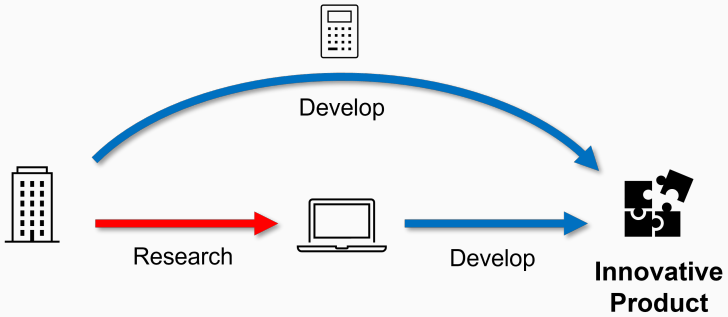
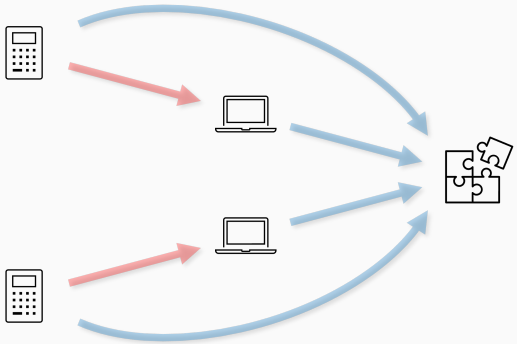
Preview of Framework

- Two paths toward the product development

▸ Further Examples



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

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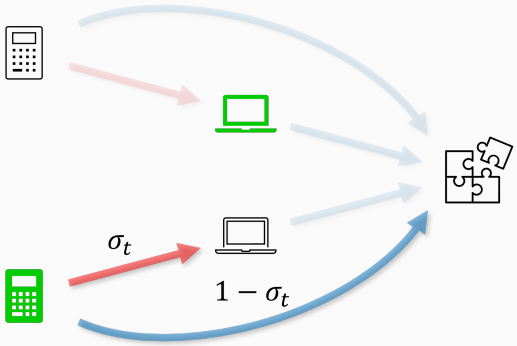

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   - Firms can observe each others' research progress
   - How would firms allocate their resources to research and development over time?
   - **Prop 1:** a firm may switch to develop with the old technology once the rival discovers the new technology

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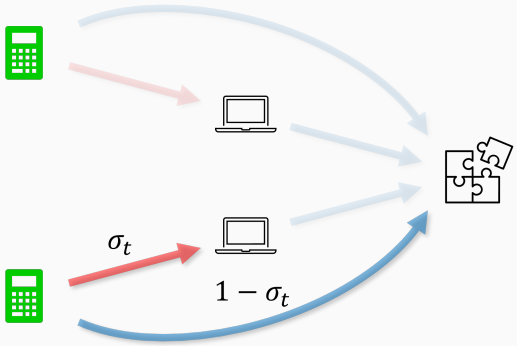

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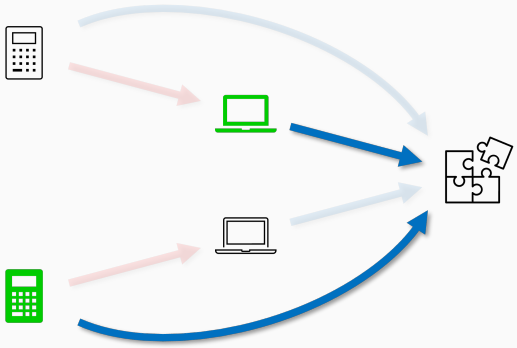

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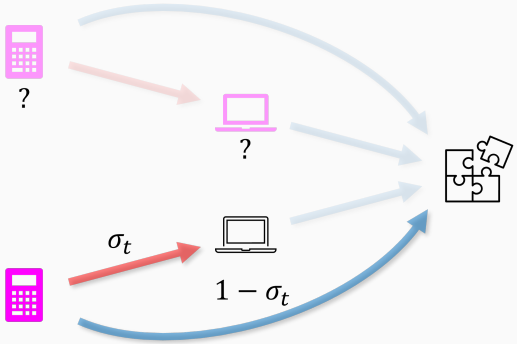

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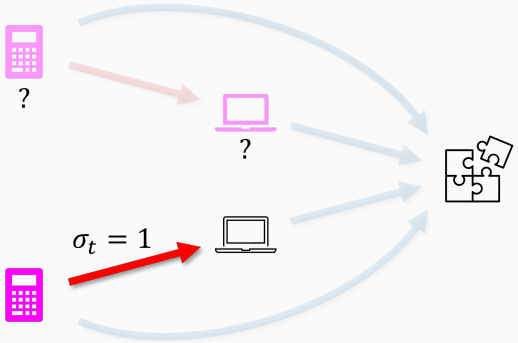

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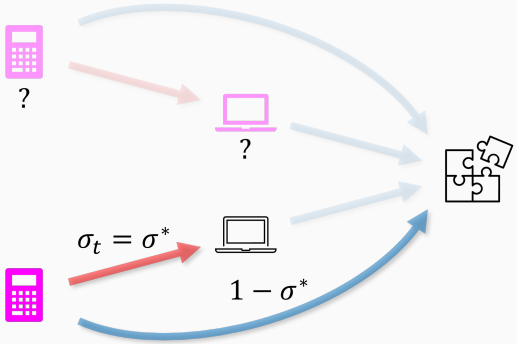

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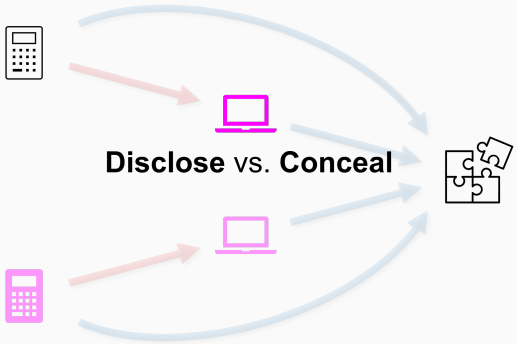

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   - Extend the private information setting by allowing firms to choose whether to disclose or conceal
   - Once patented, the firm can choose to license or not

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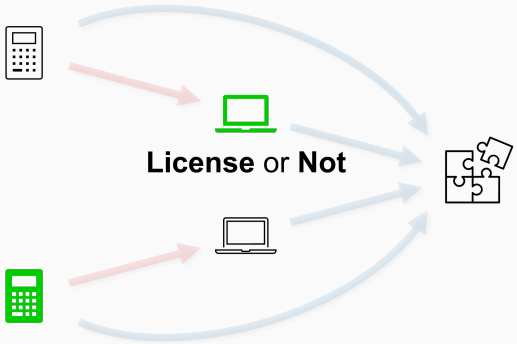

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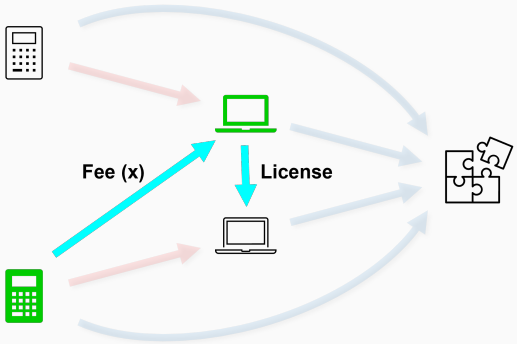

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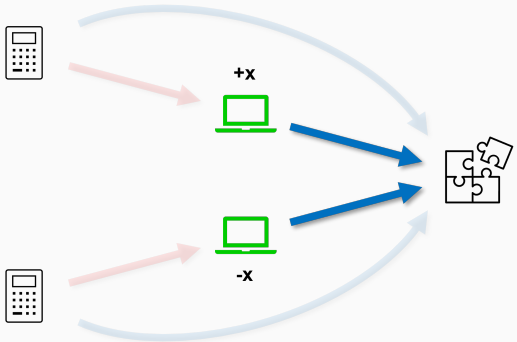

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Preview of the Main Result

	Chance of winning the race	Licensing fee
Disclosure	Lower	+
Concealment	Higher	0

- **Prop 3, 4:** Firms' disclosure decisions crucially depend on the **reward** of winning the race
  - *High* reward ⇒ firms **conceal** their discoveries ⇒ socially inefficient
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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
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- Resource allocation is not observable to the rival firm

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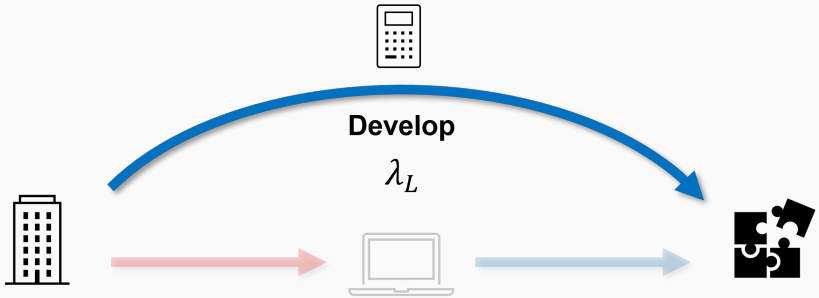

Old Technology

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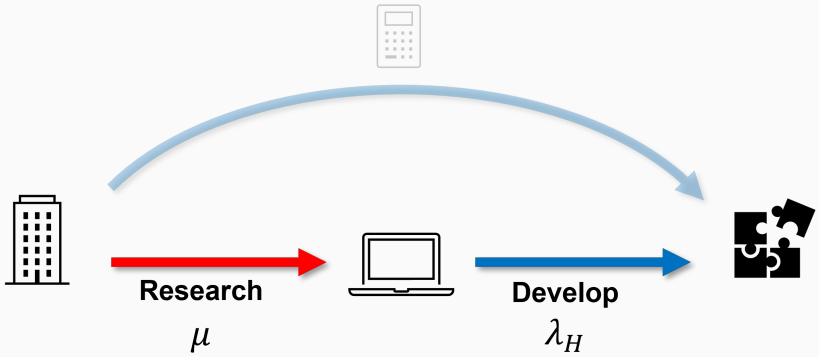

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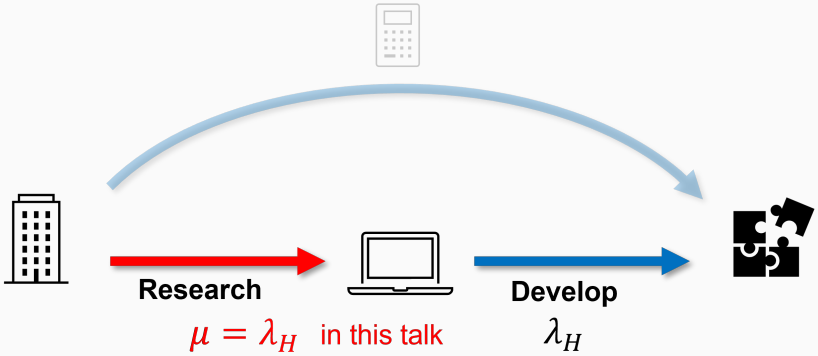

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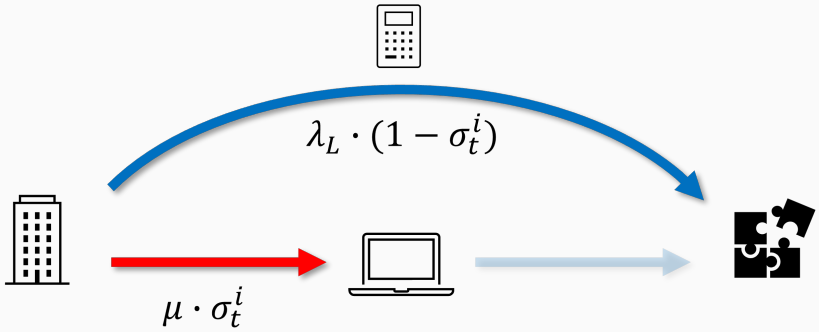
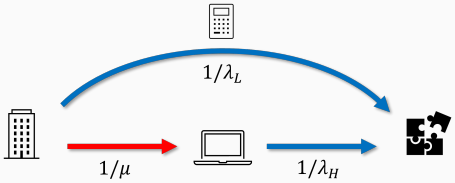


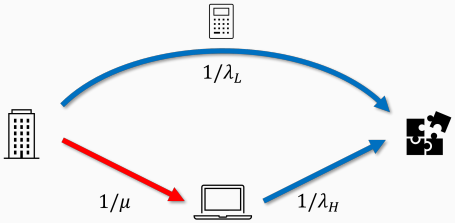
Partial Allocation

Model: Efficiency

$$\eta \equiv \frac{\mathbb{E}\left[\text{Completion time of the old tech. path}\right]}{\mathbb{E}\left[\text{Completion time of the new tech. path}\right]} = \frac{1/\lambda_L}{1/\mu + 1/\lambda_H} = \frac{\lambda_H}{2\lambda_L} > 1$$



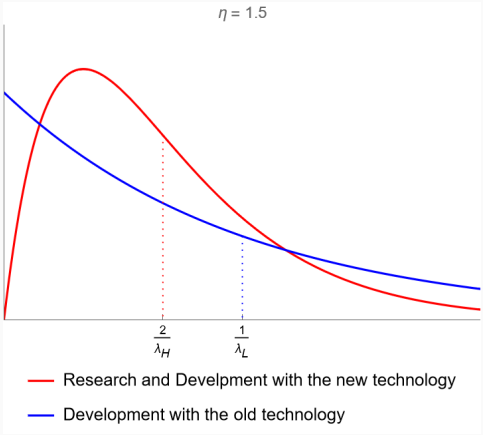
New technology is efficient ($\eta \uparrow$)



New technology is inefficient ($\eta \downarrow$)

▸ Relative Intensity (δ)

Model: Comparison between two paths



PDF of the completion time without race

Long Run:

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

Short Run:

- By comparing the prob. of completion in the near future:
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- As η decreases, research becomes less preferred

▸ Public Info. Result

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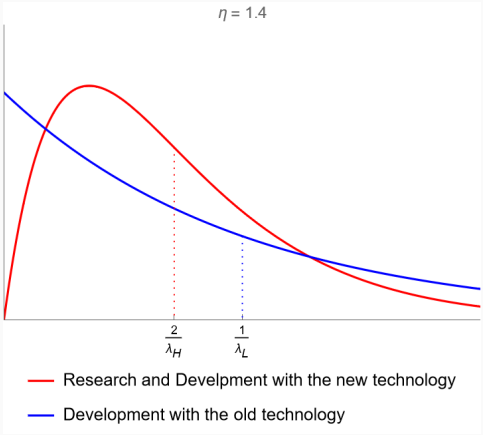

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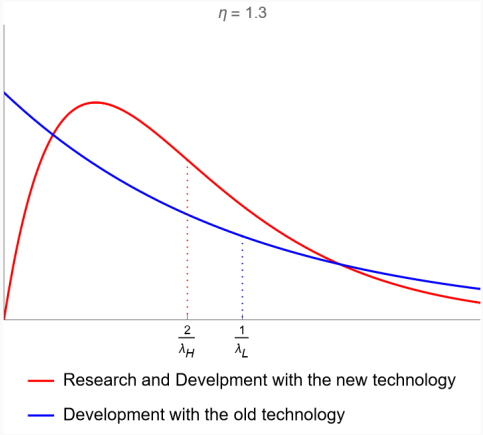

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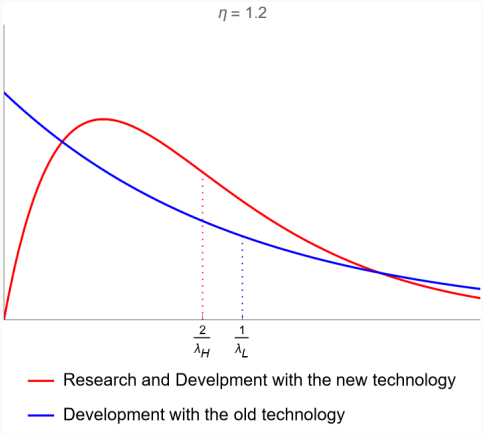

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Model: Payoffs

- 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
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- Thus, the final payoff of Firm i is:

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

where T is the time at which the race stops

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

2. Developing with the old technology is profitable:

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Low-Reward Case

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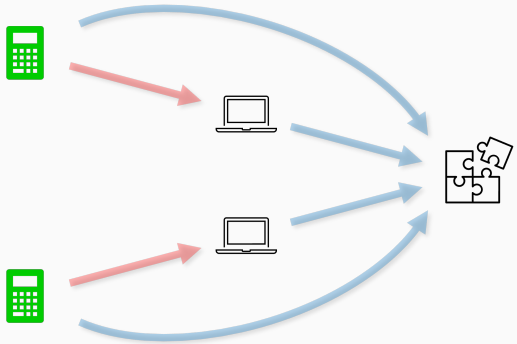
- **First-Best Case**: firms do research and the new technology is immediately shared



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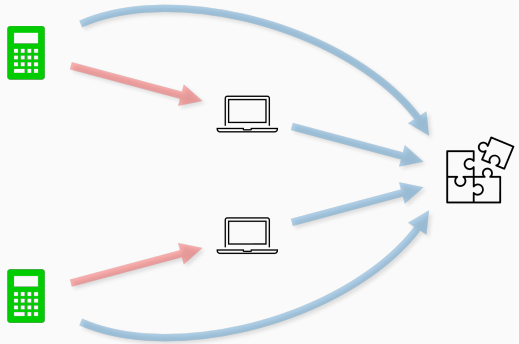

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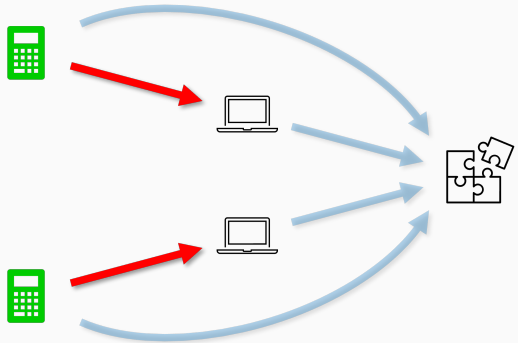

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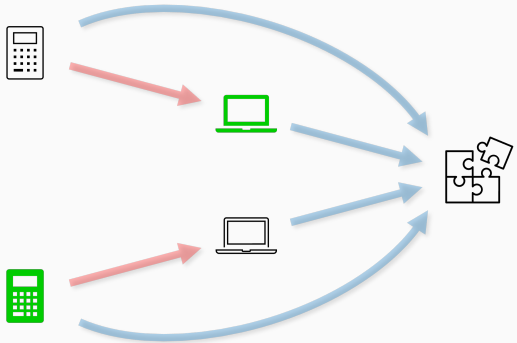

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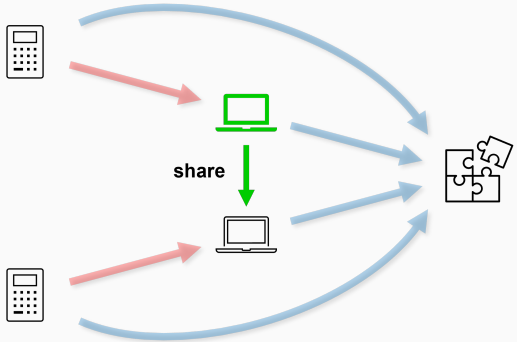

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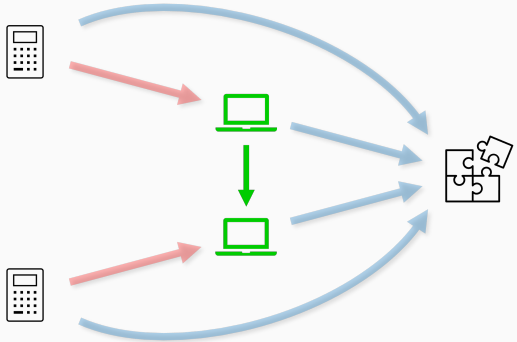

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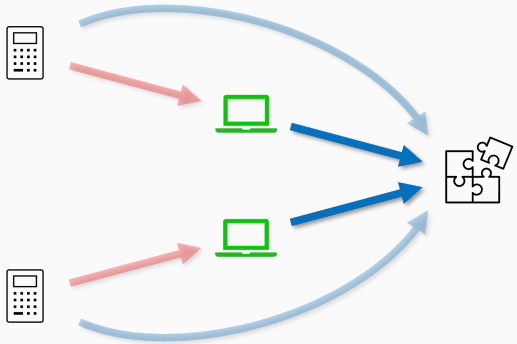

Public Information Setting

- Suppose that firms' research progress is public information
  - firms need to independently discover the new technology to utilize it
- **Strategy**: resource allocations over time contingent on the rival's progress
- **Markov strategy**
  - State variable: whether the rival has the new technology or not

▸ Formal Definitions

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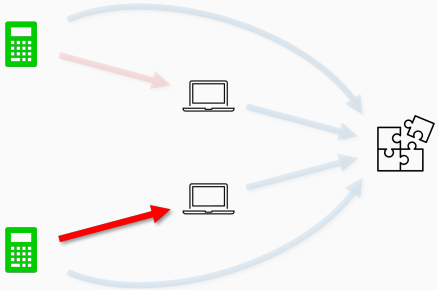
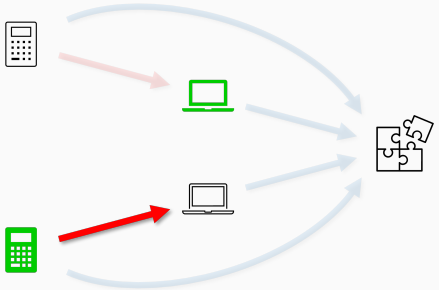
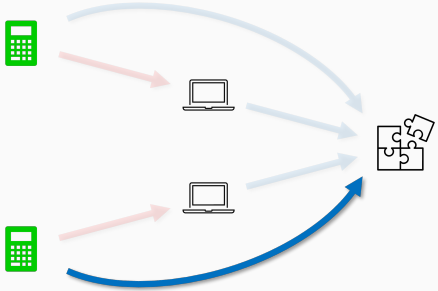
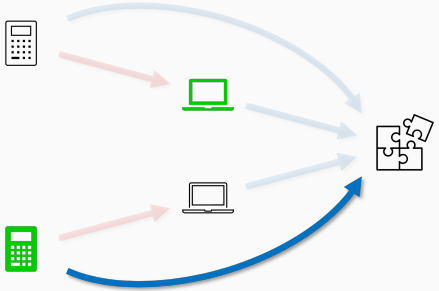




Direct-Development Strategy

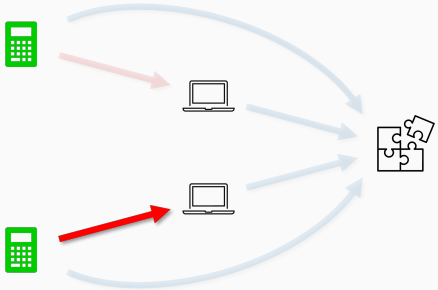
- Develop with the old technology regardless of the rival's progress

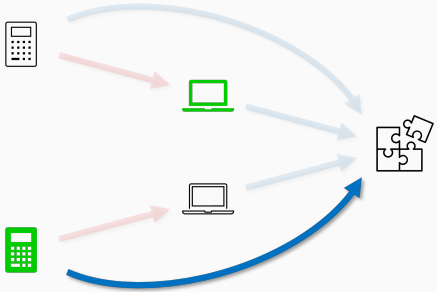




Fall-Back Strategy

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



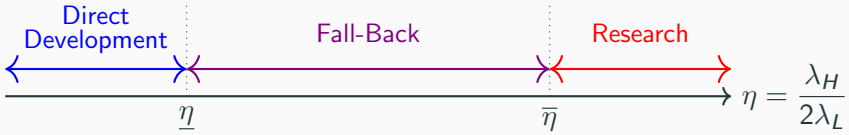


Public Information: MPE Characterization

Proposition 1

Suppose that firms' research progress is public information. Then, the unique Markov perfect equilibrium is characterized by two thresholds $\overline{\eta}$ and $\underline{\eta}$.

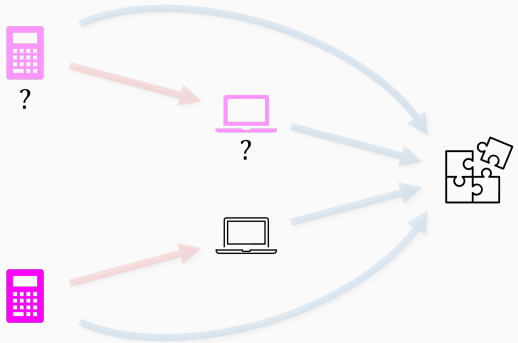
1. If $\eta > \overline{\eta}$, both firms play the research strategy;
2. If $\overline{\eta} > \eta > \underline{\eta}$, both firms play the fall-back strategy;
3. If $\underline{\eta} > \eta$, both firms play the direct-development strategy.



▸ FB Eq'm ▸ DD Eq'm ▸ Further Illustration

Private Information: Strategies

- Firms cannot observe rivals' research progress



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

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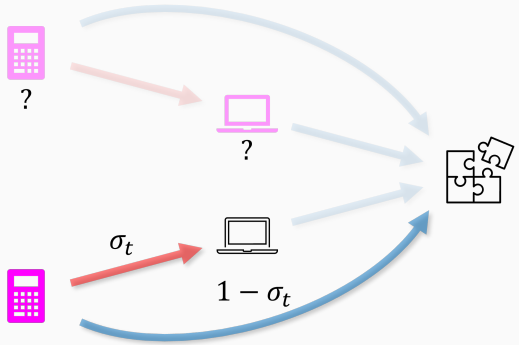

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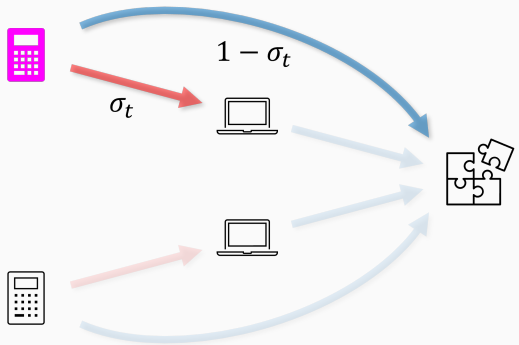
Private Information: Belief Updating

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

▸ Belief Updating



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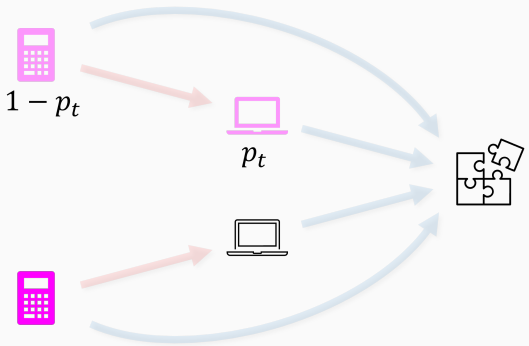


Private Information: Symmetric Markov Equilibrium

Solution concept: Symmetric Markov Equilibrium (SME)

- $\sigma_t^A = \sigma_t^B = \sigma_t$ for all $t \geq 0$;
- Sequential rationality
  - Given a strategy profile σ, the belief p_t is updated by Bayes' rule
  - At each point in time t, σ_t maximizes the expected payoff in the continuation game
- σ is a Markov strategy w.r.t. beliefs:

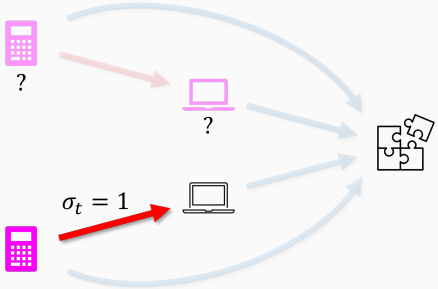
$$\sigma_t = \sigma_{t'} \qquad \text{if} \quad p_t = p_{t'}$$

▸ HJB

Stationary Fall-Back Strategy

- Fall-Back strategy is no longer feasible

When $t < T^*$



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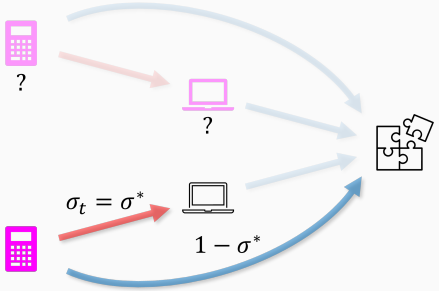

Proposition 2

Suppose that the firms' research progress is private information.

- **(Cutoff Structure)** Any SME can be characterized by a cutoff time $T^* \in \mathbb{R} \cup \{\infty\}$ and a stationary strategy $\sigma^* \in [0, 1)$:

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

  Moreover, $p_t = p^*$ for all $t \geq T^*$.

- **(Equilibrium Characterization)** There are three types of equilibria: Proof

  (i) the research strategy ($T^* = \infty$) if $\eta \geq \overline{\eta}$;

  (ii) the direct-development strategy ($T^* = 0$, $\sigma^* = 0$) if $\eta \leq \underline{\eta}$;

  (iii) the stationary fall-back strategy ($T^* \in (0, \infty)$, $\sigma^* \in (0, 1)$) if $\eta \in (\underline{\eta}, \overline{\eta})$.

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Private Information: Symmetric Markov Equilibrium

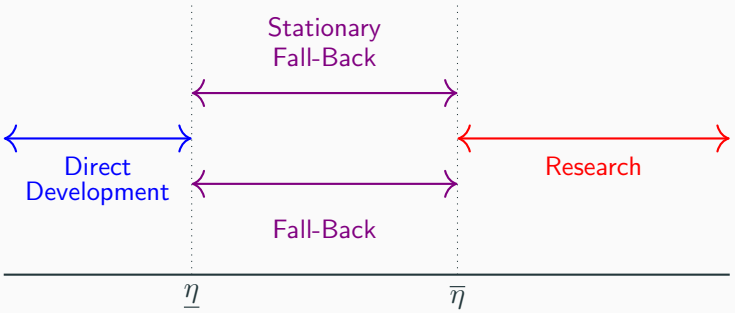


Figure: Symmetric Markov Equilibrium

▸ $\delta > 1/2$ ▸ Further Illustration

Private Information: Intuition for the Results

1. **Outside of the fall-back region**
    - When the fall-back strategy is not an MPE in the public information case, the observability does not affect the firms' resource allocations

2. **Inside the fall-back region**:

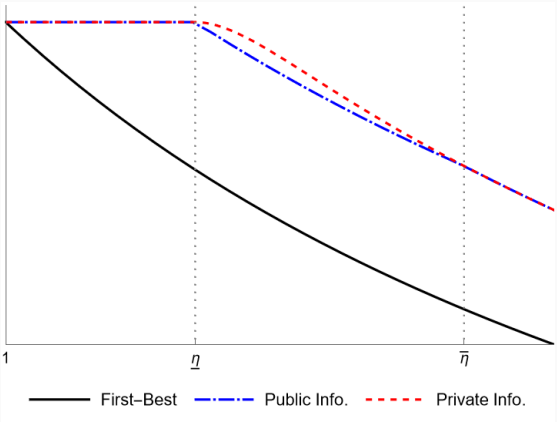
Private Information: Intuition for the Results

1. **Outside of the fall-back region**
   - When the fall-back strategy is not an MPE in the public information case, the observability does not affect the firms' resource allocations

2. **Inside the fall-back region**:
   - when both firms keep doing research, as $t \to \infty$, the belief converges to 1
   - firms *partially* switch to developing with the old technology when p is close to 1
   - find p^* and σ^* that equalize DE and SRE, and make indifferent between doing research and developing with the old technology

▸ Details

Expected Completion Time



1. **FB vs. Public Info**
   Absence of technology sharing
2. **Public vs. Private Info**
   Lack of information transmission about research progress

▸ Go Back

Disclosure vs. Concealment

- Extend the private information setting by allowing firms to choose
  - *concealing* the new technology and protect it by using a **trade secret**
  - *disclosing* the new technology and protect it by using a **patent**

    (it is also possible to conceal the new technology for a certain period and then disclose it)
  - once a firm acquires a patent, it can choose to **license** it or not

▸ Formal Definitions

- Restrict attention to the case with $\eta \in (\underline{\eta}, \overline{\eta})$

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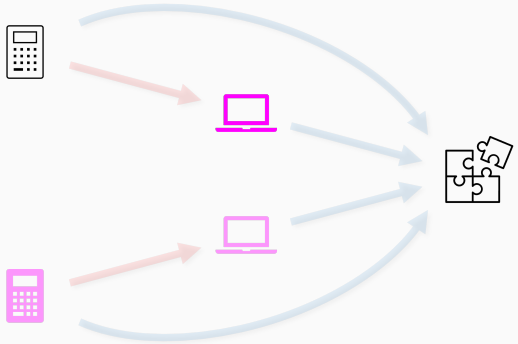
Trade Secret

- The rival cannot observe whether the firm has discovered the new technology
- This does not prohibit the rival from discovering it independently



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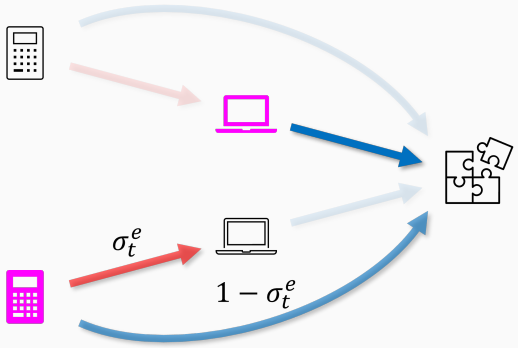

Patent and License

- When a firm files a patent, it discloses the discovery of the new technology
- This gives the exclusive right to use the new technology
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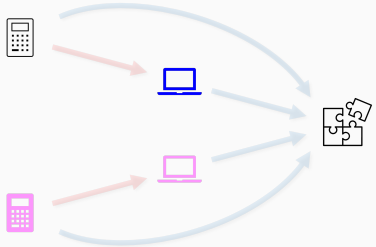
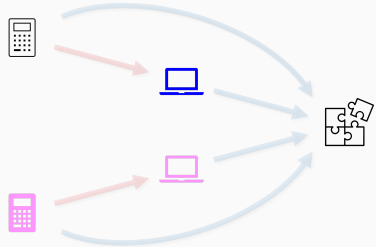
- The firm may **license** the technology (the patenting firm makes a TIOLI offer)





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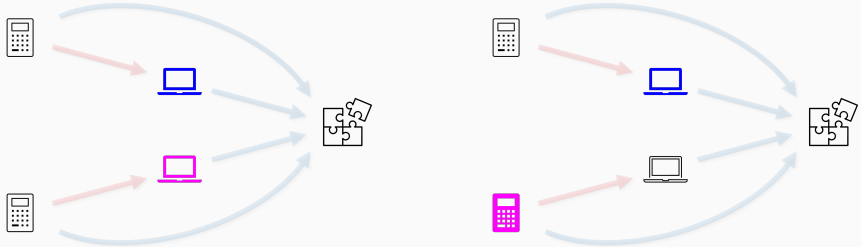

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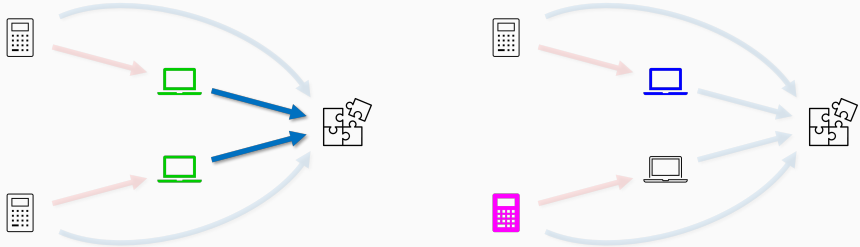

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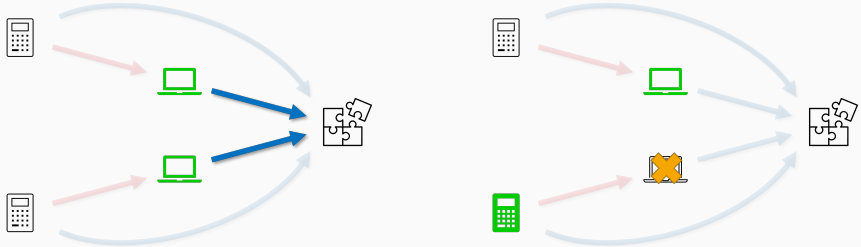

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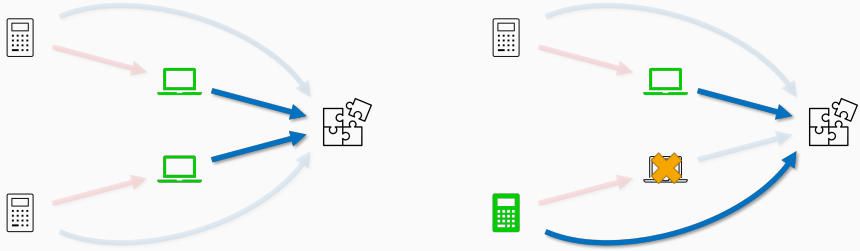

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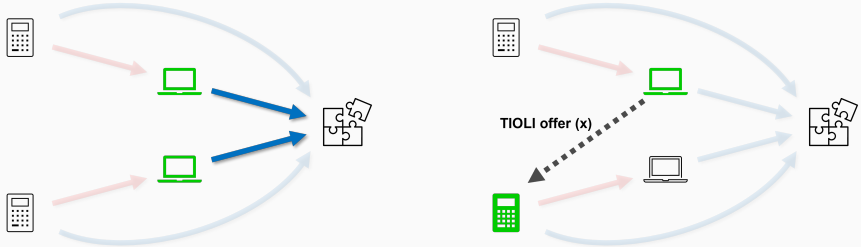

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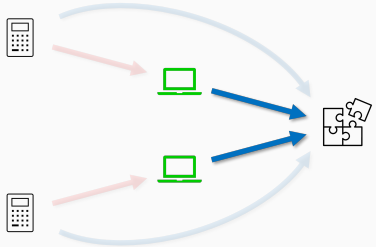
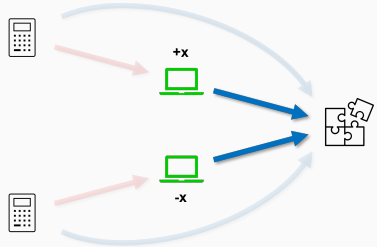




Disclosure vs. Concealment: Low Reward

Proposition 3

Suppose that $\eta \in (\underline{\eta}, \overline{\eta})$. There exists Π_0 such that for all $\Pi \leq \Pi_0$, the *research-and-immediate-disclosure* strategy constitutes an equilibrium:

- firms fully allocate their resources to research ($\sigma_t = 1$ for all $t \geq 0$);
- firms immediately files a patent and then licenses it.

▸ Proof Sketch

Disclosure vs. Concealment: High Reward

Proposition 4

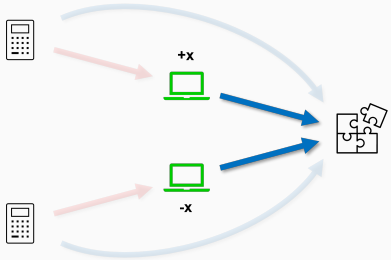
Suppose that $\eta \in (\underline{\eta}, \overline{\eta})$. There exists $\Pi_1 \geq \Pi_0$ such that for all $\Pi \geq \Pi_1$, the *stationary-fall-back-and-no-disclosure* strategy constitutes an equilibrium:

- firms use the stationary fall-back strategy in the private info. setting: ($\sigma_t = 1$ for all $0 \leq t \leq T^*$ and $\sigma_t = \sigma^*$ for all $t > T^*$);
- firms never disclose their discoveries

▸ Proof Sketch

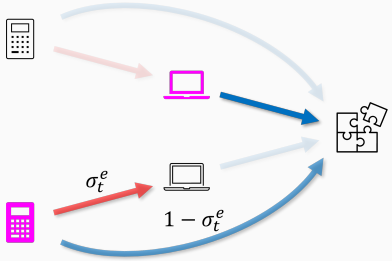
Disclosure vs. Concealment

Patent (then License)



- Lower chance of winning the race
- Immediate license fee

Trade Secret



- Higher chance of winning the race
- No license fee

Disclosure vs. Concealment: Takeaways

- Firms' disclosure decisions crucially depend on the reward of winning the race (Π)
  - When Π is *small*, the new technology is licensed as soon as a firm discovers
    (Outcome is equivalent to the **First-Best** case)
  - When Π is *high*, firms conceal their discoveries
    (Outcome is equivalent to the **Private Information** case)

▸ Expected Completion time

- **Implications**
  - The first-best outcome can be achieved by lowering Π
    (e.g., imposing tax in the innovative product market)
  - This result is opposite to the standard view that a higher reward may accelerate the innovation
  - Caveat: too low Π may induce the firms to exit the race

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1. Introduction

2. Model

3. Public Information Setting

4. Private Information Setting

5. Disclosure vs. Concealment

6. 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
  - Prize of winning the race $\uparrow$
    $\Rightarrow$ Incentives to conceal $\uparrow$ (to increase chances to win)
    $\Rightarrow$ Innovation speed $\downarrow$

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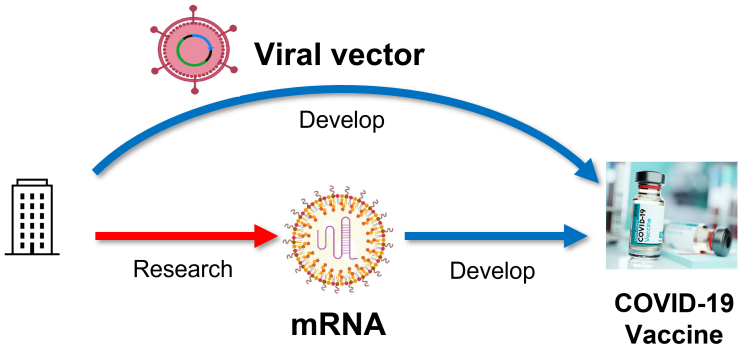
Thank you!

Preview of Framework: Further Examples



https://pubs.acs.org/doi/10.1021/acsnano.0c07197

https://www.cdc.gov/coronavirus/2019-ncov/vaccines/different-vaccines/overview-COVID-19-vaccines.html

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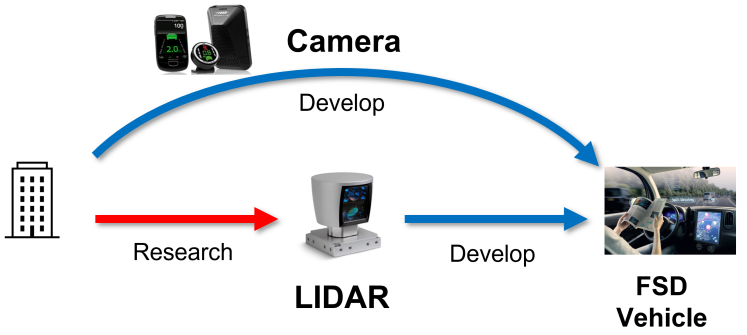

https://www.templetons.com/brad/robocars/cameras-lasers.html

https://www.pbs.org/newshour/science/in-a-crash-should-self-driving-cars-save-passengers-or-pedestrians-2-million-people-weigh-in

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Hall, Helmers, Rogers, and Sena, JEL 2014, p.381

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	Prod.: 5.4* Proc.: 5.1*	Prod.: 57% Prod.: 56%	Prod.: 54% Proc.: 47%	Prod.: 53% Prod.: 38%	88%	Prod.: 67% Prod.: 46%	Prod.: JP 41%; US 52% Proc.: JP 28%, US 38%
or	Patents	High: pharma Low: pulp, paper	High: pharma/ chemicals/petroleum Low: basic metals	n.a.	High: medical equipment, pharma Low: printing/ publishing	High: rubber & plastic, biotech Low: construction/mining	High: pharma Low: prod.: utilities; proc.: electrical equip.	n.a.

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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)

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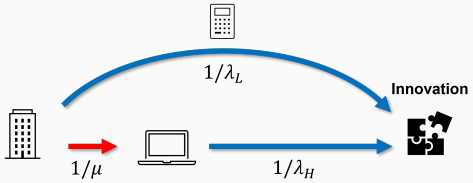
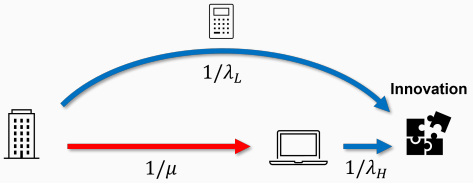
Model: Relative Intensity

$$\delta \equiv \frac{\mathbb{E}\left[\text{Research Completion time w/ new tech.}\right]}{\mathbb{E}\left[\text{(Total) Completion time w/ new tech.}\right]} = \frac{1/\mu}{1/\mu + 1/\lambda_H} = \frac{\lambda_H}{\lambda_H + \mu}.$$





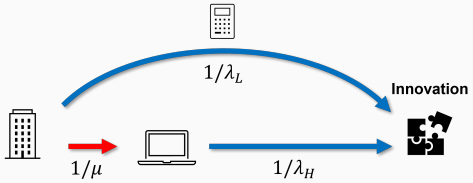
New technology is development intensive ($\delta \downarrow$)

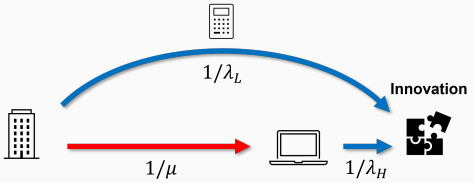
New technology is research intensive ($\delta \uparrow$)

▸ Go Back

Model: Relative Intensity

$$\delta \equiv \frac{\mathbb{E}\left[\text{Research Completion time w/ new tech.}\right]}{\mathbb{E}\left[\text{(Total) Completion time w/ new tech.}\right]} = \frac{\lambda_H}{\lambda_H + \mu} = \frac{1}{2} \quad \text{in this talk.}$$





New technology is development intensive ($\delta \downarrow$)

New technology is research intensive ($\delta \uparrow$)

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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.

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Formal Definitions of Strategies

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

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

- **Markov Strategy**

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

- 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 $\sigma_i(\{j\}) = 0.$

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Public Information: MPE Characterization

Proposition

Suppose that firms can observe the other firm's technological progress. Then, the unique Markov perfect equilibrium is characterized as follows.

1. If $\eta \geq \overline{\eta}(\delta) \equiv 1 + \delta$, both firms play the research strategy;
2. If $1 + \delta > \eta > \underline{\eta}(\delta) \equiv \frac{1}{2}\left(1 + \sqrt{1 + 4\delta(1-\delta)}\right)$, both firms play the fall-back strategy;
3. If $\underline{\eta}(\delta) \geq \eta$, both firms play the incumbent strategy.

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Public Information: MPE Illustration

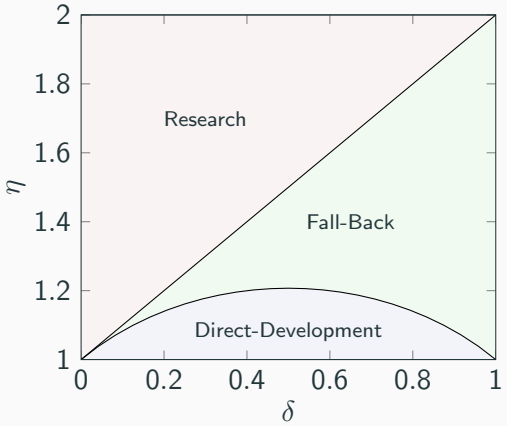

Figure 1: MPE with observable technology.

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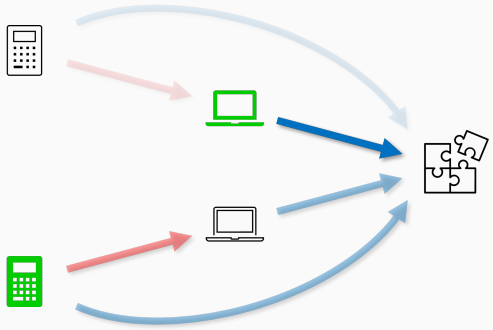
Public Information: Intuition for the Fall-Back Equilibrium



- Recall that development may be preferred over research in the short run when η is small ▸ SR Intuition
- Firm B knows that Firm A is likely to end the race soon
  $\Rightarrow \exists\, \overline{\eta}$ such that the best response for Firm B is to:

$$\begin{cases} \text{do research}, & \text{if } \eta > \overline{\eta}, \\ \text{develop}, & \text{if } \eta < \overline{\eta}, \end{cases}$$

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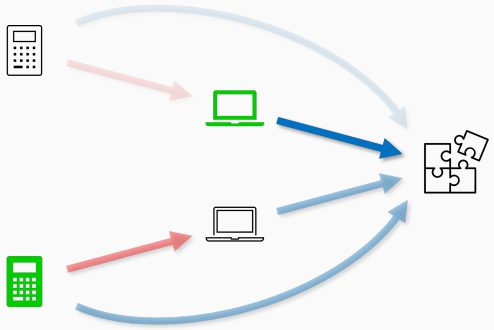

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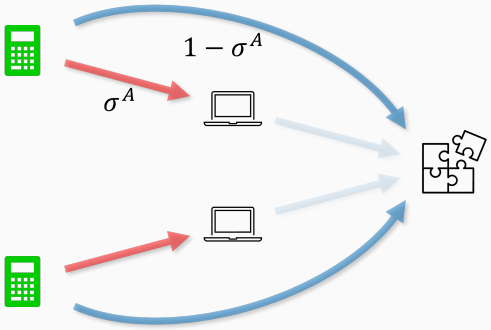
Public Information: Intuition for the Direct-Development Equilibrium



- There exists $\underline{\eta} < \overline{\eta}$ such that the best response of Firm B for any given $\sigma^A \in [0,1]$ is to:

$$\begin{cases} \text{do research}, & \text{if } \eta > \underline{\eta}, \\ \text{develop}, & \text{if } \eta < \underline{\eta}, \end{cases}$$

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Private Information: Evolution of Beliefs

- p_t^i : 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 σ^j, p_t^i is characterized by the initial condition $p_0^i = 0$ and

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

- **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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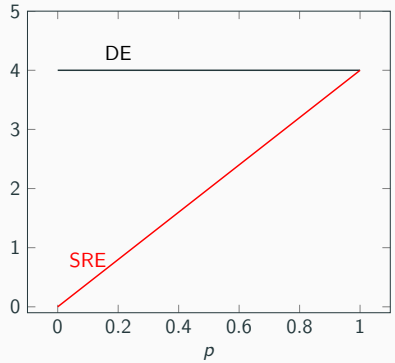

Duration Effect (Black) and Still-in-the-Race Effect (Red)
for $\sigma^j = 1$, $\lambda_L = 1$, $\mu = \lambda_H = 4$

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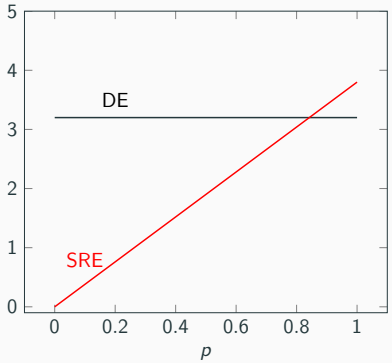
Private Information: Evolution of Beliefs



Mechanic Effect (Black) and Still-in-the-Race Effect (Red)
for $\sigma^j = .8$, $\lambda_L = 1$, $\mu = \lambda_H = 4$

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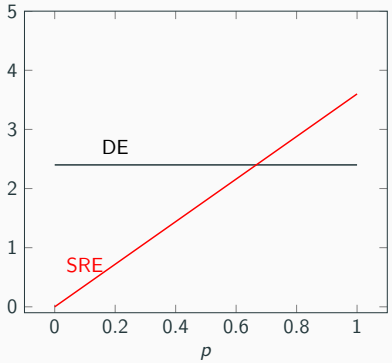
Private Information: Evolution of Beliefs



Mechanic Effect (Black) and Still-in-the-Race Effect (Red)
for $\sigma^j = .6$, $\lambda_L = 1$, $\mu = \lambda_H = 4$

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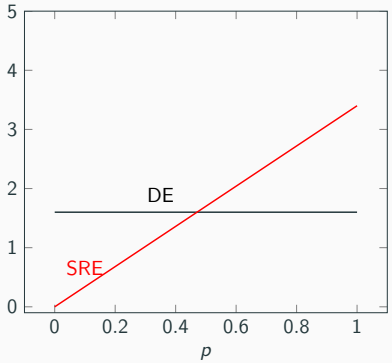
Private Information: Evolution of Beliefs



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

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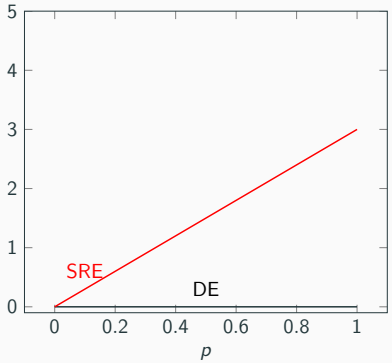
Private Information: Evolution of Beliefs



Mechanic Effect (Black) and Still-in-the-Race Effect (Red)
for $\sigma^j = 0$, $\lambda_L = 1$, $\mu = \lambda_H = 4$

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Private Information: Symmetric Markov Equilibrium

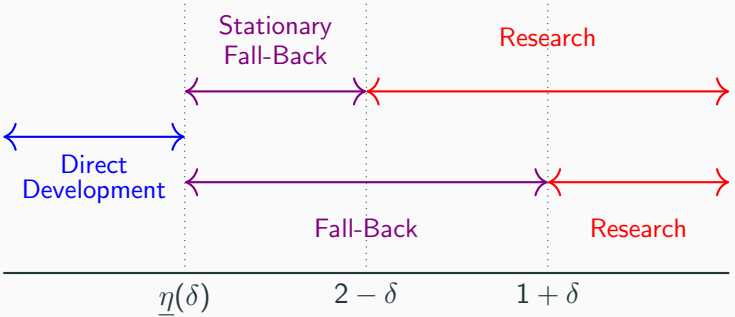

Figure: SME when $\delta > 1/2$

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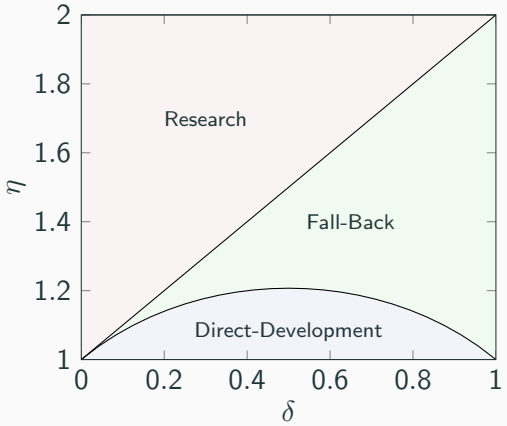
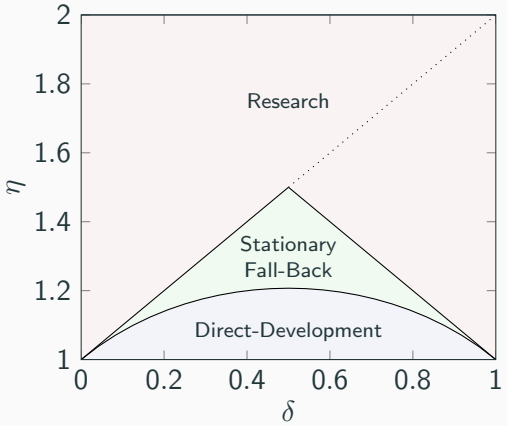
Private Information: Symmetric Markov Equilibrium



(a) Public Information Setting



(b) Private Information Setting

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Private Information: HJB Equations

- $V_T^{1,i}$: the expected payoff of Firm i (w/ new tech.) at time T

$$0 = \dot{V}_T^{1,i} + \lambda_H(\Pi - V_T^{1,i}) - \left\{\lambda_H p_T^i + \lambda_L(1-p_T^i)(1-\sigma_T^j)\right\} V_T^{1,i} - c. \quad (\text{HJB}_1)$$

- $V_T^{0,i}$: the expected payoff of Firm i (w/o new tech.) at time T

$$\begin{aligned} 0 = \dot{V}_T^{0,i} &- \left\{\lambda_H p_T^i + \lambda_L(1-p_T^i)(1-\sigma_T^j)\right\} V_T^{0,i} - c \\ &+ \max\{\mu(V_T^{1,i} - V_T^{0,i}), \lambda_L(\Pi - V_T^{0,i})\}. \end{aligned} \quad (\text{HJB}_0)$$

- Best Responses
  - (a) $\sigma_T^i = 1$ if $\mu(V_T^{1,i} - V_T^{0,i}) > \lambda_L(\Pi - V_T^{0,i})$
  - (b) $\sigma_T^i = 0$ if $\mu(V_T^{1,i} - V_T^{0,i}) < \lambda_L(\Pi - V_T^{0,i})$
  - (c) $\sigma_T^i \in [0,1]$ if $\mu(V_T^{1,i} - V_T^{0,i}) = \lambda_L(\Pi - V_T^{0,i})$

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Private Information: Proof Sketch

1. If the belief process $\{p_t\}$ is derived from a symmetric Markov strategy σ,

$$\dot{p}_t \geq 0 \quad \forall t \geq 0.$$

$\because$ (i) $p_0 = 0$; (ii) if $\dot{p}_t < 0$ for some $t > 0$, by Markov property, the belief cannot go above p_t which contradicts $\dot{p}_t < 0$.

2. (a) $\sigma_t = 0$ for all $t \geq 0$ or
   (b) $\sigma_t > 0$ for all $t \geq 0$.

3. If σ constitutes an SME and $\sigma_S \in (0, 1)$ for some $S \geq 0$,
   then the firms are indifferent between research and development for all $t \geq S$.

4. If σ constitutes an SME and firms are indifferent between R&D for all $t \geq T$,
   then $\sigma_t = \sigma^*$ and $p_t = p^*$ for all $t \geq T$.

5. By the above results, there are three types of SME:
   (a) $\sigma_t = 0$ for all $t \geq 0$ ($T^* = 0$ and $\sigma^* = 0$)

Private Information: Proof Sketch

1. $\dot{p}_t \geq 0$ for all $t \geq 0$
2. If σ constitutes an SME,
   (a) $\sigma_t = 0$ for all $t \geq 0$ or
   (b) $\sigma_t > 0$ for all $t \geq 0$.

   $\because$ if $p_t > 0$ and $\sigma_t = 0$, $\dot{p}_t < 0$
3. If σ constitutes an SME and $\sigma_S \in (0, 1)$ for some $S \geq 0$,
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   (b) $\sigma_t = 1$ for all $t \geq 0$ ($T^* = \infty$)
   (c) $\sigma_t = 1$ for some $0 \leq T^* < \infty$ and $\sigma_t = \sigma^*$

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6. Identify parametric regions where each strategy constitutes an SME

▸ Go Back

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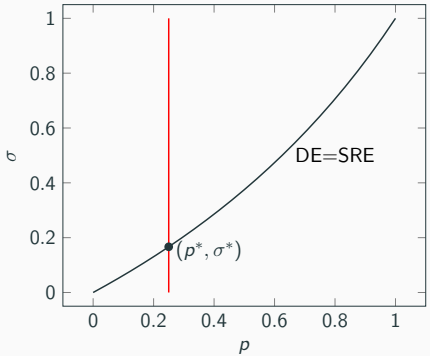

Identifying (p^*, σ^*)
for $\lambda_L = 2$, $\mu = \lambda_H = 5$

- DE and SRE are equalized when

$$\sigma^S(p) = \frac{(\lambda_H - \lambda_L)p}{\mu - \lambda_L p}$$

- If both firms employ $\sigma^S(p)$ at the belief p, the expected payoffs are:

$$V_1^S(p) = \frac{\lambda_H \Pi - c}{\lambda_H + \lambda_H p + \lambda_L(1-\sigma^S(p))(1-p)}$$
$$V_0^S(p) = \frac{\lambda_L(1-\sigma^S(p))\Pi + \mu\sigma^S(p)V_1^S(p) - c}{\mu\sigma^S(p) + \lambda_H p + \lambda_L(1-\sigma^S(p))\{1+(1-p)\}}$$

- Indifference condition:

$$\mu(V_1^S(p) - V_0^S(p)) = \lambda_L(\Pi - V_0^S(p))$$

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Disclosure vs. Concealment: Formal Definitions

- A firm's disclosing rule can be described as follows:
  - When a firm discovers at t, it chooses a survival function H_t

    $$H_t(t') = \text{ prob. that the discovery has not been disclosed by time } t' \ (\geq t)$$

  - $H_t : [t, \infty) \to [0, 1]$ is right-continuous and non-increasing.
- **Benchmark rules**
  - *Immediate disclosure rule*: $H_t^I(t) = 0$ for all $t \geq 0$
  - *No disclosure rule*: $H_t^N(t') = 1$ for all $t' \geq t \geq 0$
  - (λ, T)*-partial disclosure rule*:

$$H_t^{\lambda,T}(t') = \begin{cases} 1, & \text{if } \max\{t, T\} \geq t', \\ e^{-\lambda(t'-T)}, & \text{if } \max\{t, T\} < t'. \end{cases}$$

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Sketch of Proof

Suppose that Firm A discovered the new technology.

- If Firm B already has the new technology, Firm A's choice does not matter
- If Firm B does not have the new technology,
  - V_P: Firm A's expected payoff of patenting without licensing
  - V_L: Firm A's expected payoff of patenting with licensing
  - V_S: Firm A's expected payoff of concealing forever (under the stationary phase)
- As Π increases

$$V_L - V_P = \frac{\lambda_H - \lambda_L}{2(\lambda_H + \lambda_L)\lambda_H} c \quad \text{remains constant}$$

$$V_S - V_P \propto \left(\Pi - \frac{c}{\lambda_H} \right) \quad \text{increases}$$

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  $V_L - V_P = \dfrac{\lambda_H - \lambda_L}{2(\lambda_H + \lambda_L)\lambda_H} c$ remains constant

  $V_S - V_P \propto \left(\Pi - \dfrac{c}{\lambda_H}\right)$ increases

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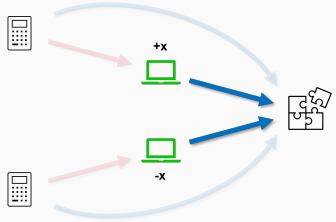
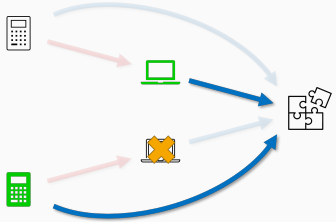
Patent and License

Patent with Licensing (L)



$$SW_L = \Pi - \frac{2c}{2\lambda_H}$$

Patent w/o Licensing (P)



$$SW_P = \Pi - \frac{2c}{\lambda_H + \lambda_L}$$

- $V_L - V_P = SW_L - SW_P = \dfrac{\lambda_H - \lambda_L}{2(\lambda_H + \lambda_L)\lambda_H} c$ (saving of the development cost)

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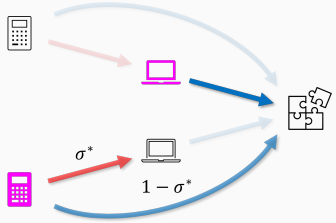
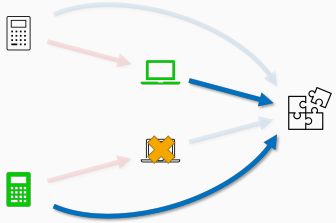
Patent and Trade Secret

Trade Secret (S)



$$V_S = \frac{\lambda_H}{\lambda_H + \lambda^*}\left(\Pi - \frac{c}{\lambda_H}\right)$$

Patent w/o Licensing (P)



$$V_P = \frac{\lambda_H}{\lambda_H + \lambda_L}\left(\Pi - \frac{c}{\lambda_H}\right)$$

- $V_S - V_P \propto \left(\Pi - \frac{c}{\lambda_H}\right)$: By concealing the new technology, the firm can hinder the rival from adjusting the strategy $\Rightarrow$ raises the chance to win the race ($\eta \in (\underline{\eta}, \overline{\eta})$)

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Trade Secret: Algebra

$$\lambda^* = \frac{\lambda_H \left(\frac{\mu\sigma^*}{2} + \lambda_L(1-\sigma^*) \right)}{\lambda_H + \frac{\mu\sigma^*}{2}}$$

- With some algebra, we can show that $\lambda^* < \lambda_L$ is equivalent to $\eta < \overline{\eta}$.
- Therefore, $V_S > V_P$ under $\eta \in (\underline{\eta}, \overline{\eta})$.

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