

# **Strategic Concealment in Innovation Races**

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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

# 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 ↑ → Competition ↑ → Innovation Speed ↑
  - This paper: No
    - due to the strategic concealment of intermediate research findings

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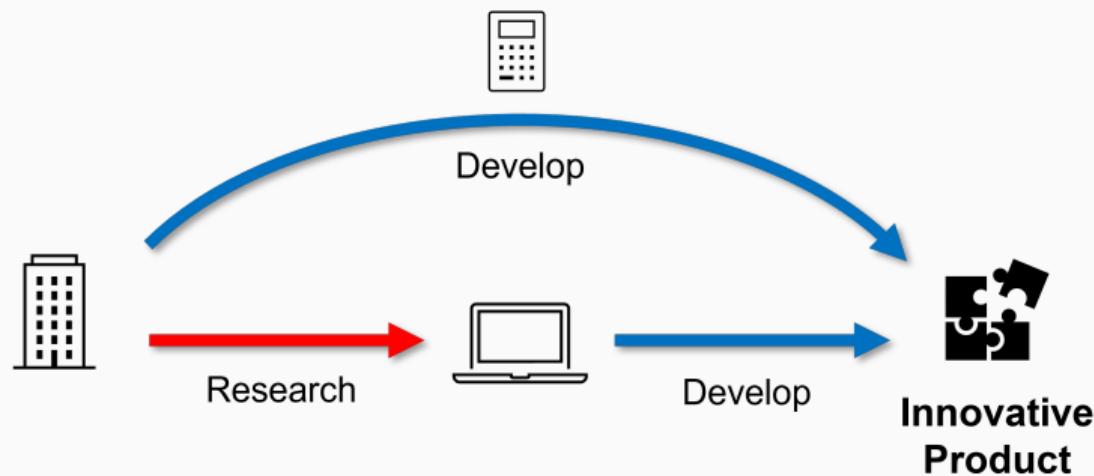
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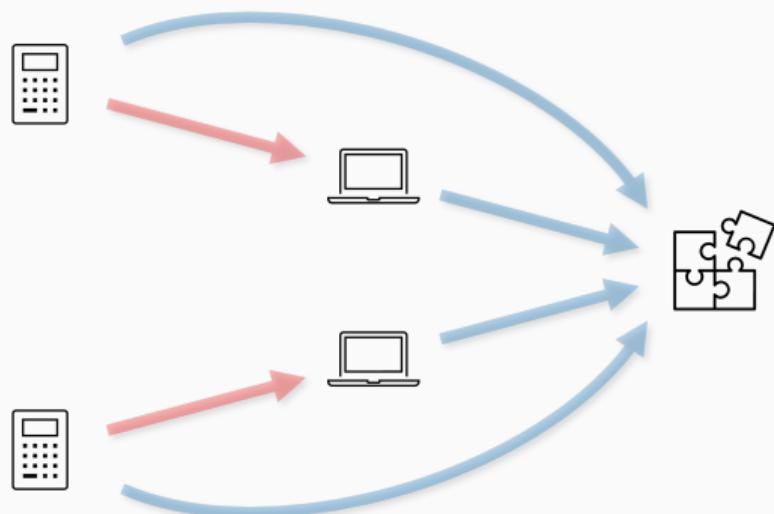
# Preview of Framework

- Two paths toward the product development

▶ Further Examples

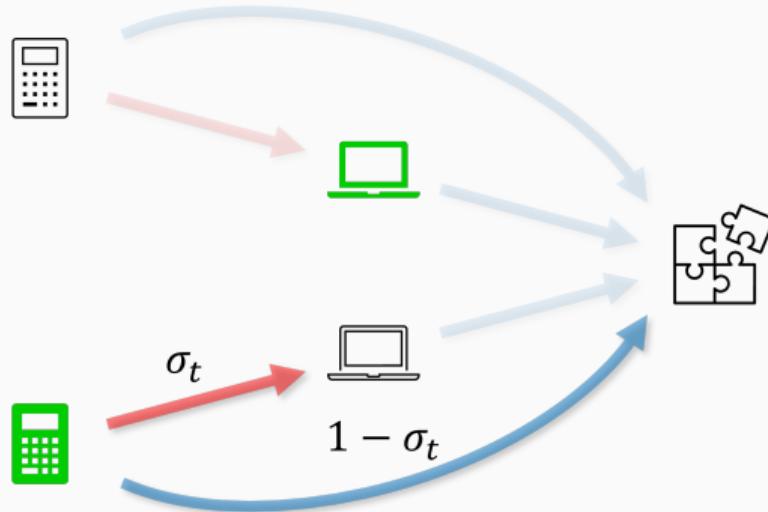


## Preview of Settings and Results



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

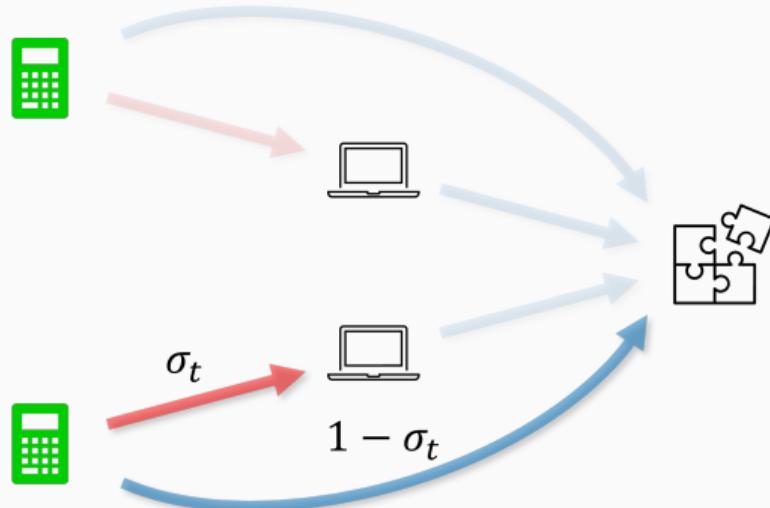
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## 1. Public Information Setting

- 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

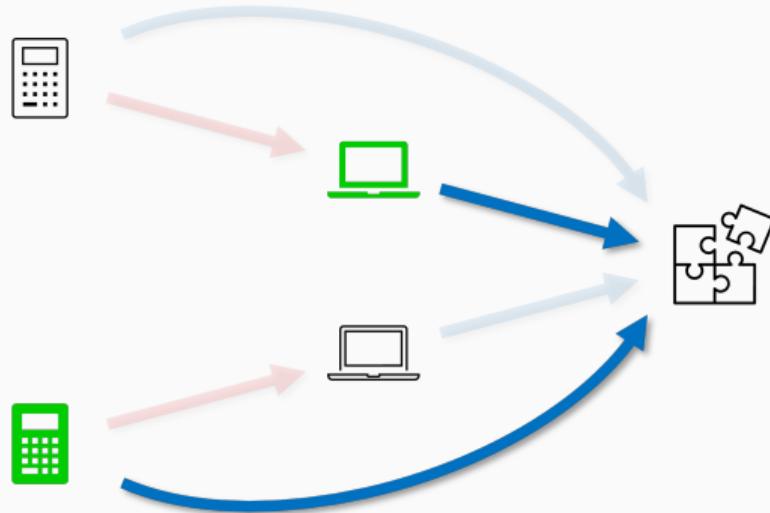
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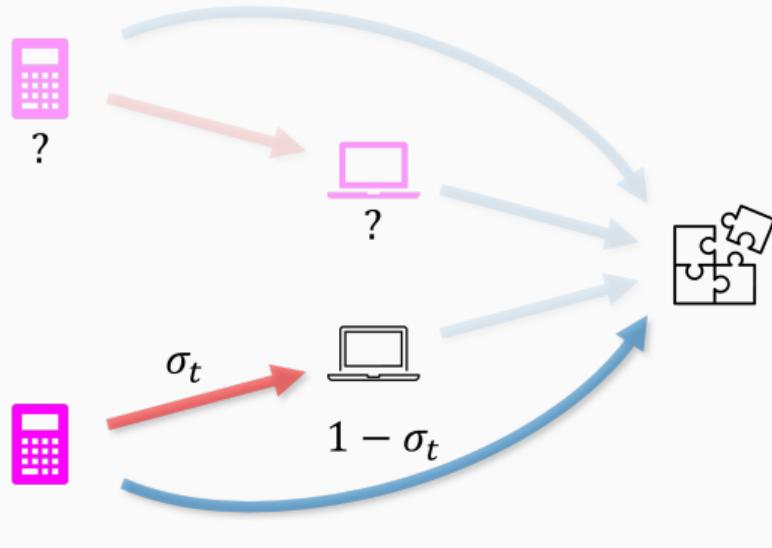
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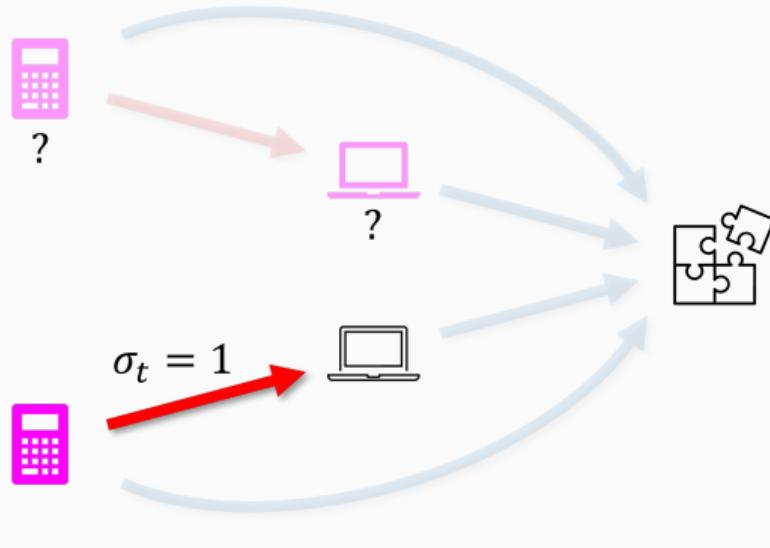


## 2. Private Information Setting

- Firms cannot observe each others' research progress
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- **Prop 2:**  $\exists T$  such that

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

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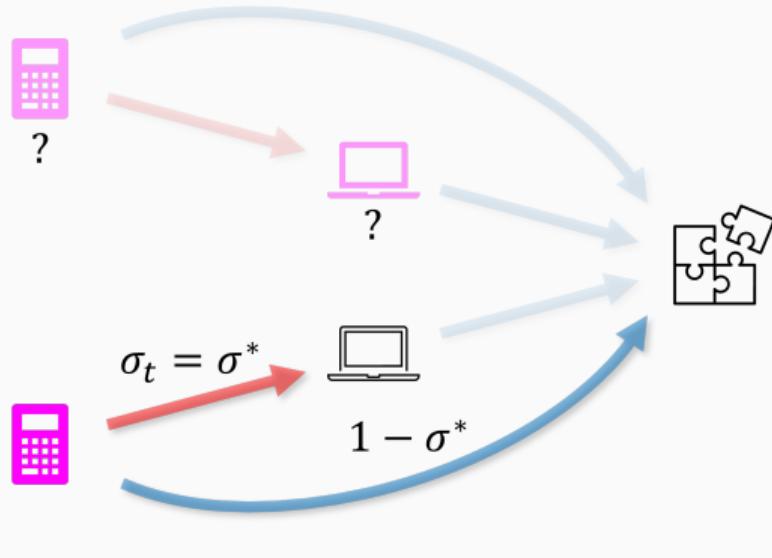


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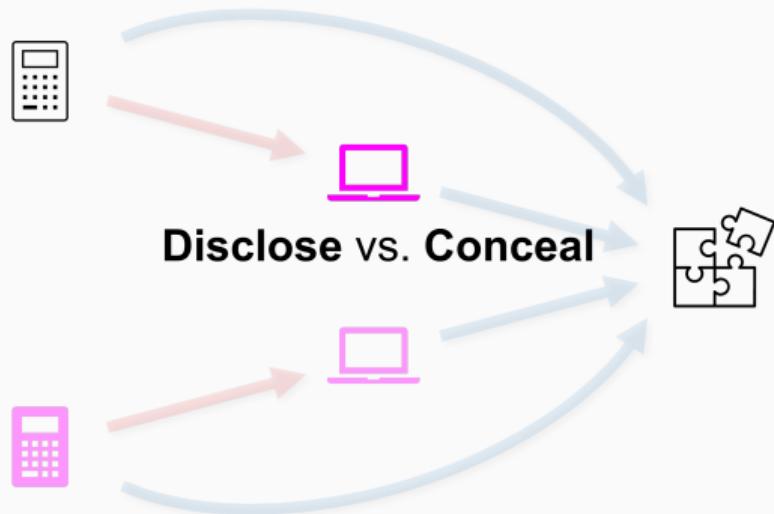


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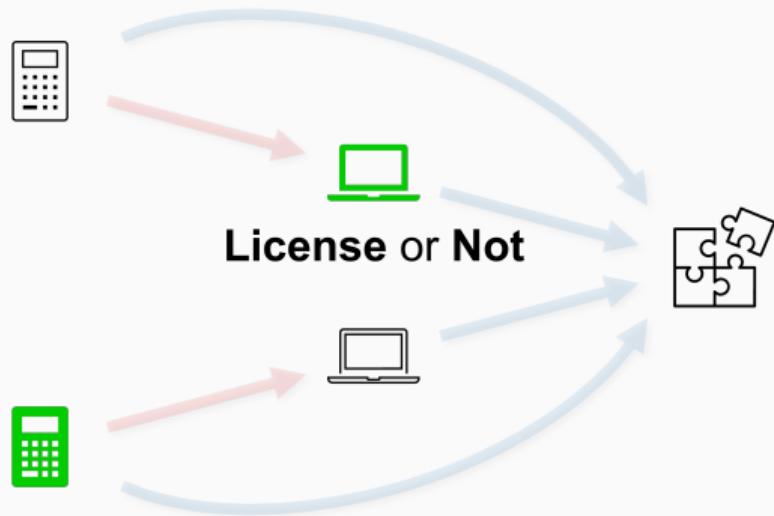
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## 3. Disclosure vs. Concealment

- 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

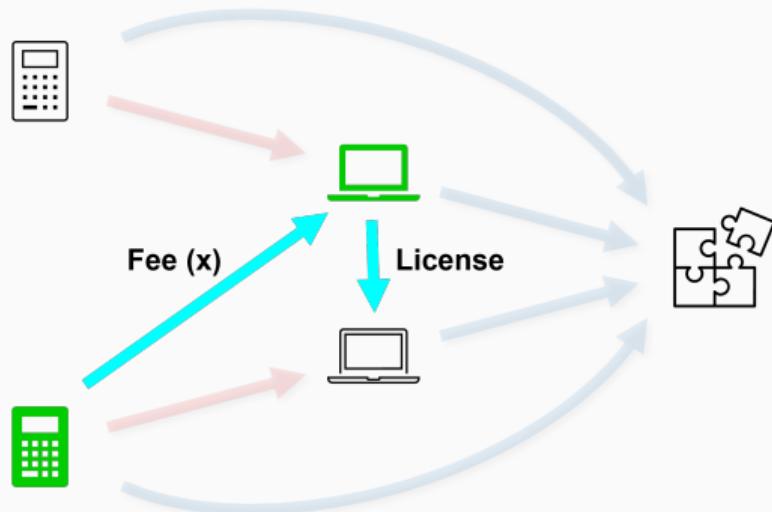
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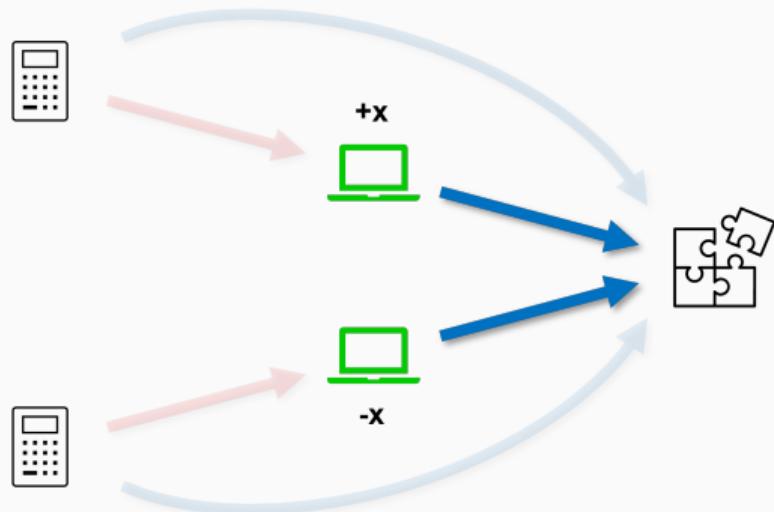
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## Preview of the Main Result

	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  $\Rightarrow$  firms **conceal** their discoveries  $\Rightarrow$  socially inefficient
  - *Low* reward  $\Rightarrow$  firms file **patents** and **license**  $\Rightarrow$  socially desirable

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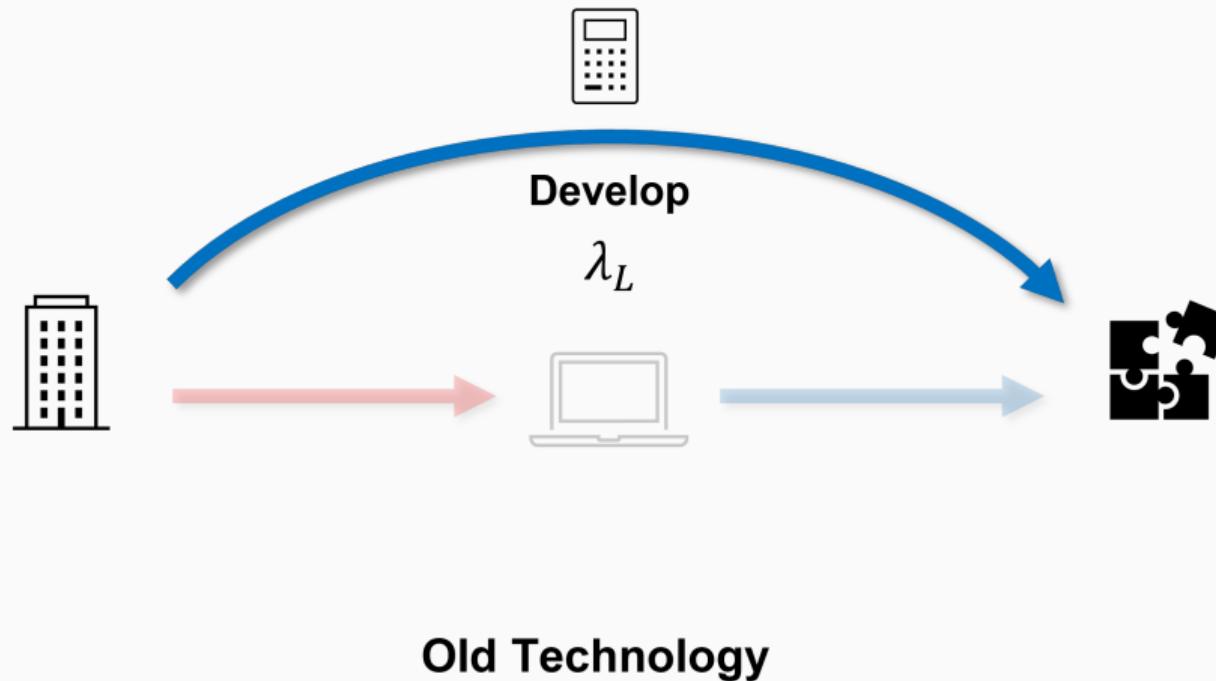
## Model: Preliminaries

- 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 innovate:
  - 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  $\sigma_t^i$
  - Development  $(1 - \sigma_t^i)$
- Resource allocation is not observable to the rival firm

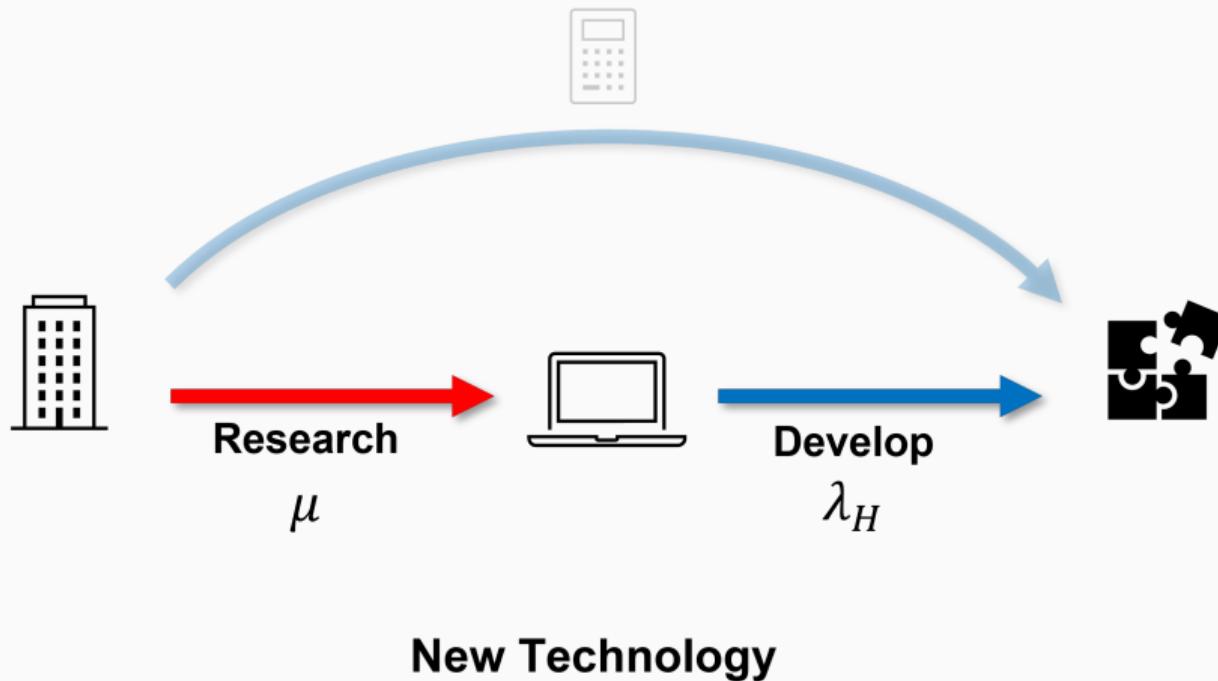
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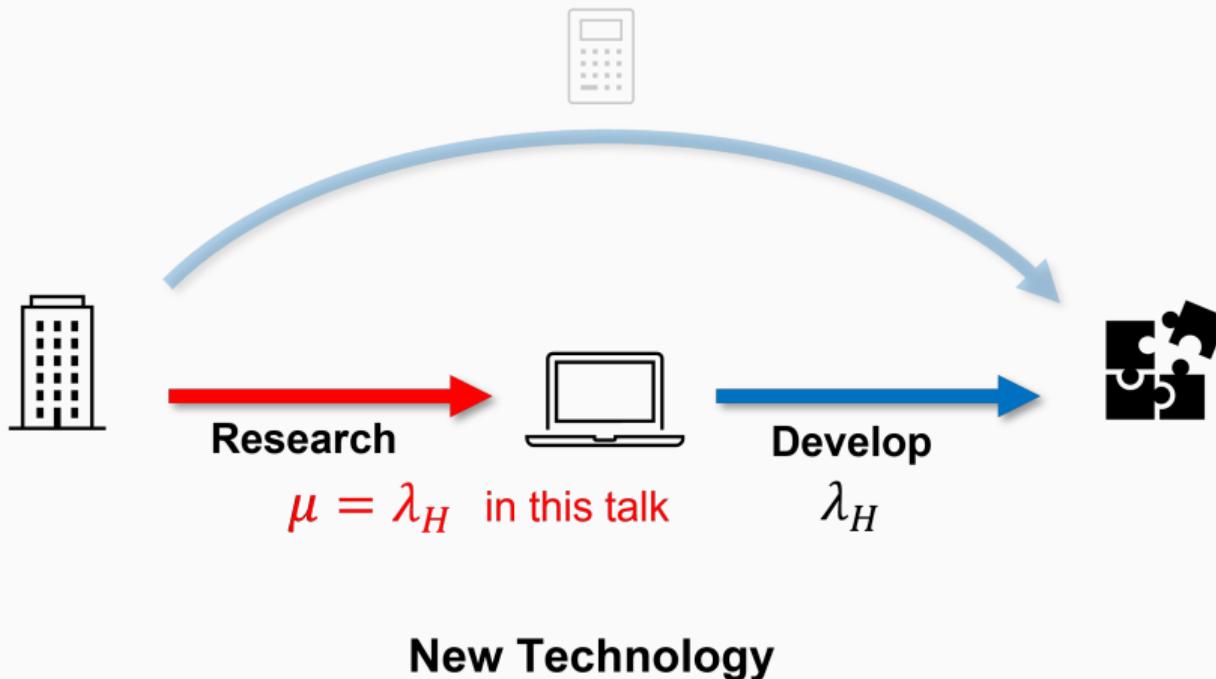
## Model: Technology Illustrations



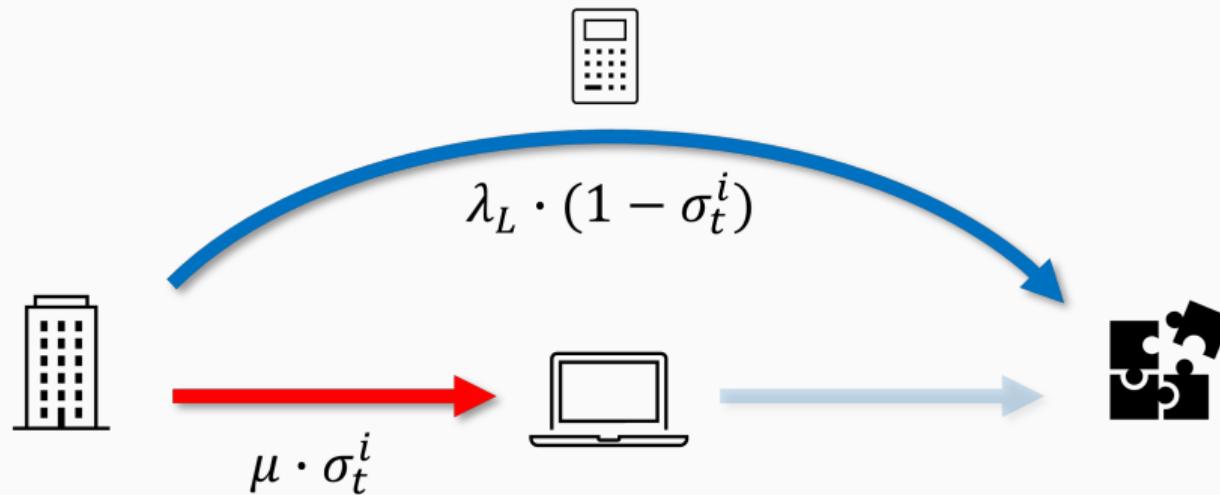
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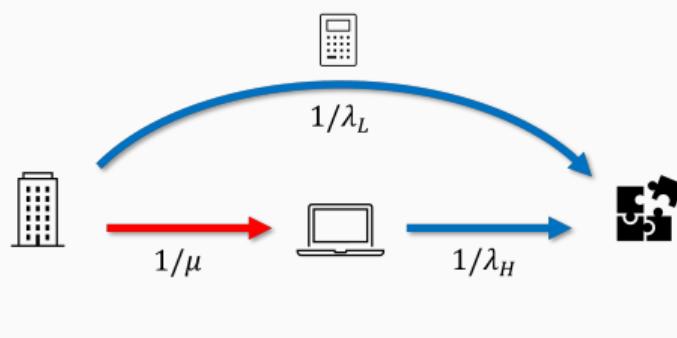
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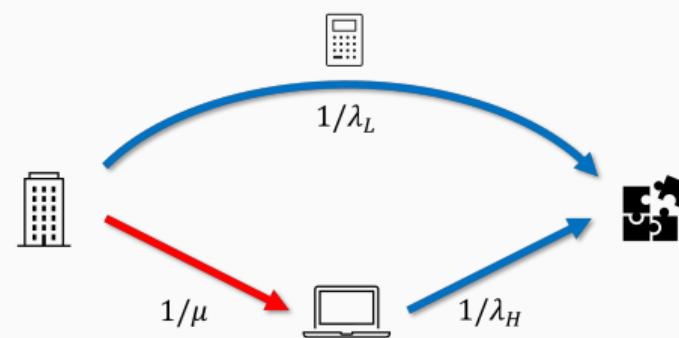
**Partial Allocation**

## Model: Efficiency

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

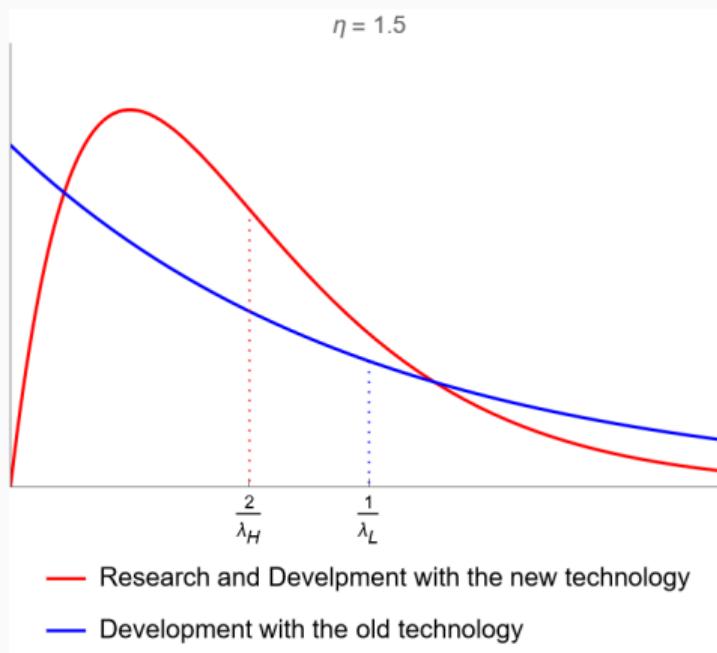


New technology is efficient ( $\eta \uparrow$ )



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

## Model: Comparison between two paths



PDF of the completion time without race

### Long Run:

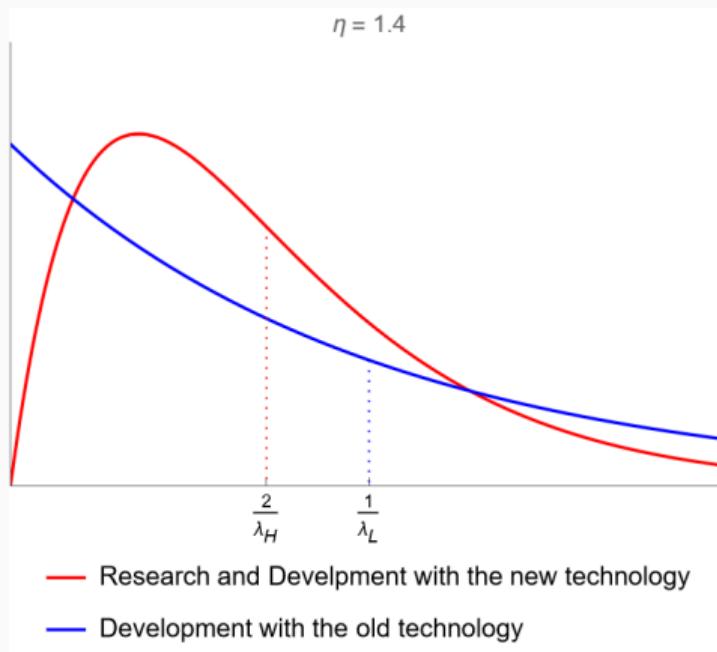
- By comparing the expected completion time:  
**Research  $\succ$  Development**

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- By comparing the prob. of completion in the near future:  
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▶ Public Info. Result

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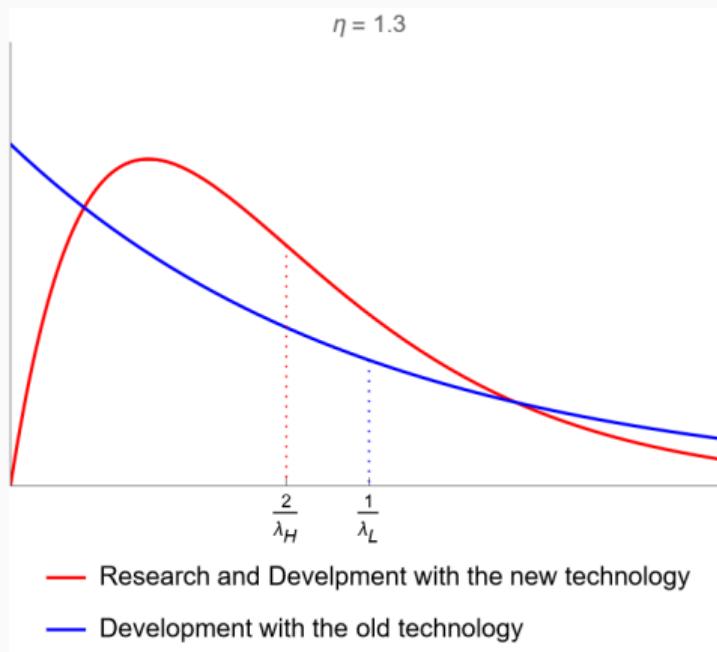
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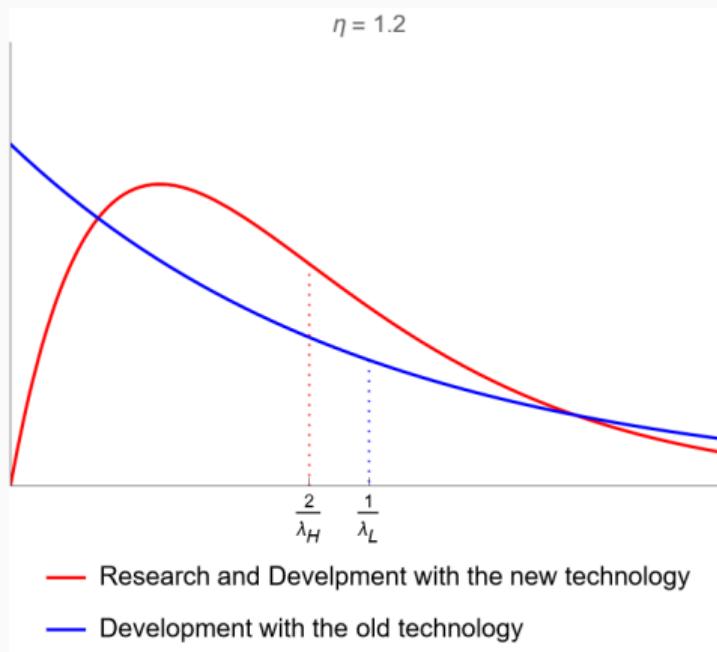
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## Model: Payoffs

- The first firm to successfully develop the innovative product receives  $\Pi$ 
  - e.g.,  $\Pi$  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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1. The new technology path ( $R + D$ ) is more efficient than the old technology path:

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

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

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

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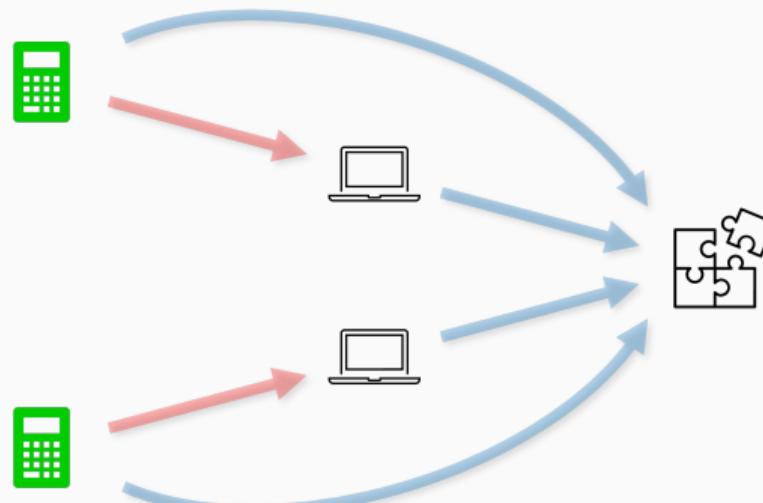
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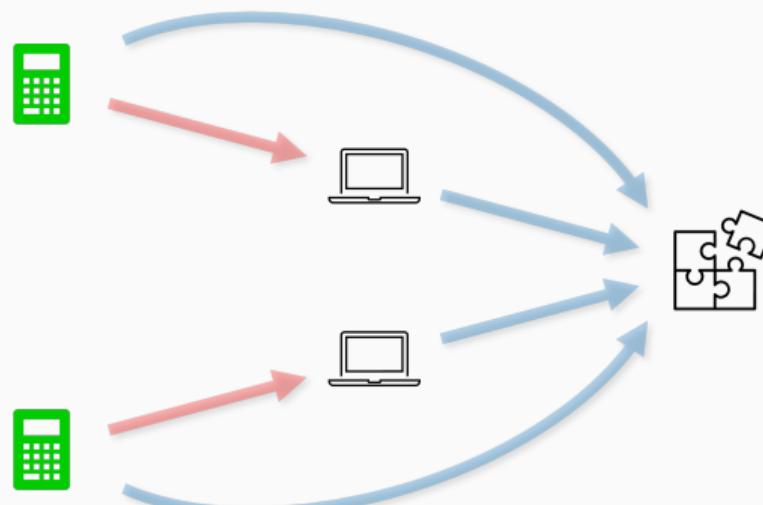
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- Planner's goal is to *max* joint profit  $\Leftrightarrow \min$  expected completion time
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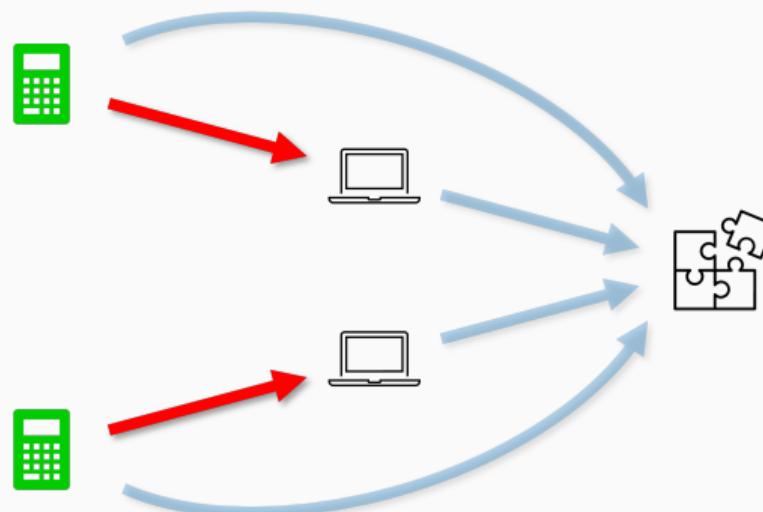
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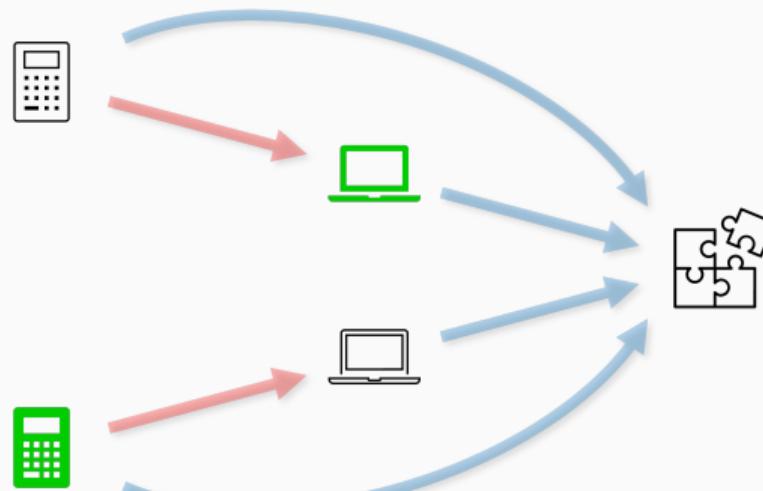
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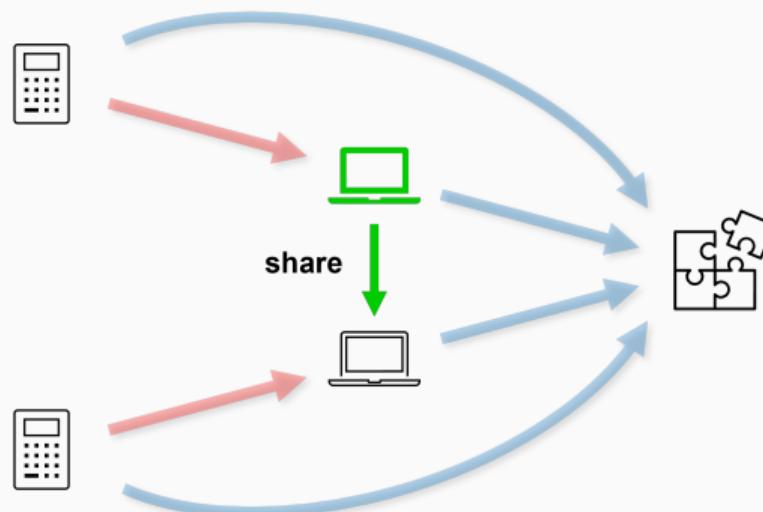
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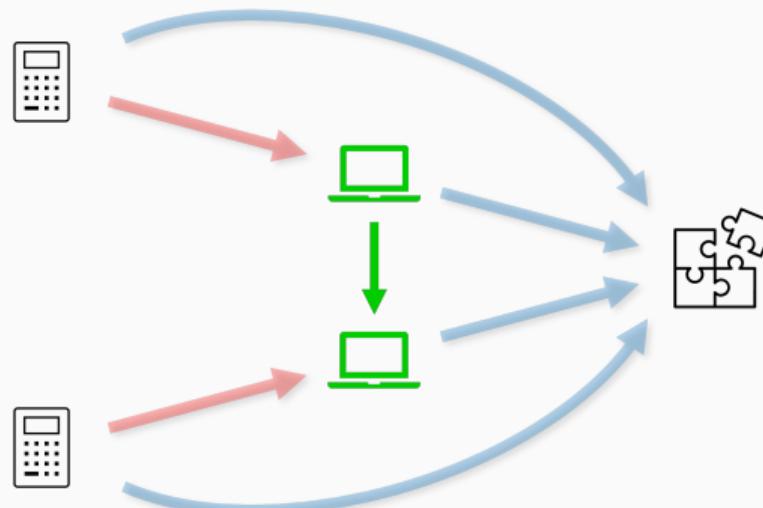
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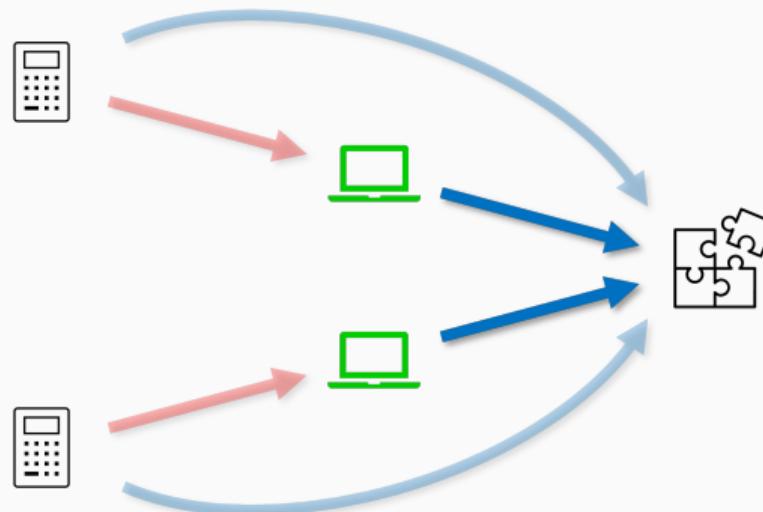
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**3. Public Information Setting**

4. Private Information Setting

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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

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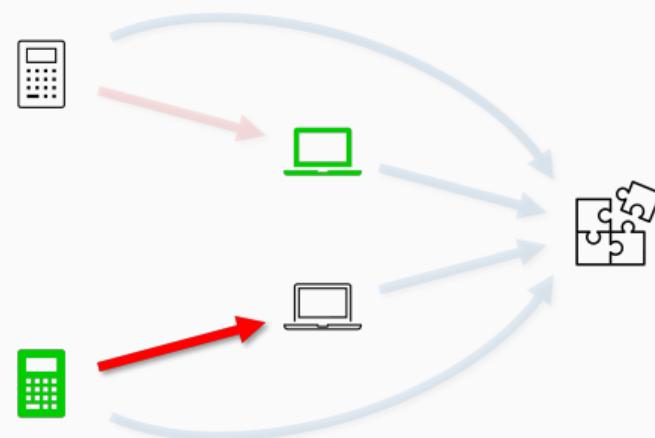
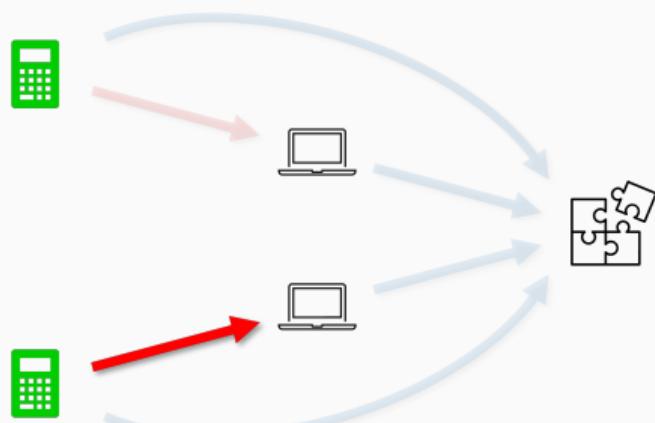
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# Benchmark Strategy 1: Research Strategy

## Research Strategy

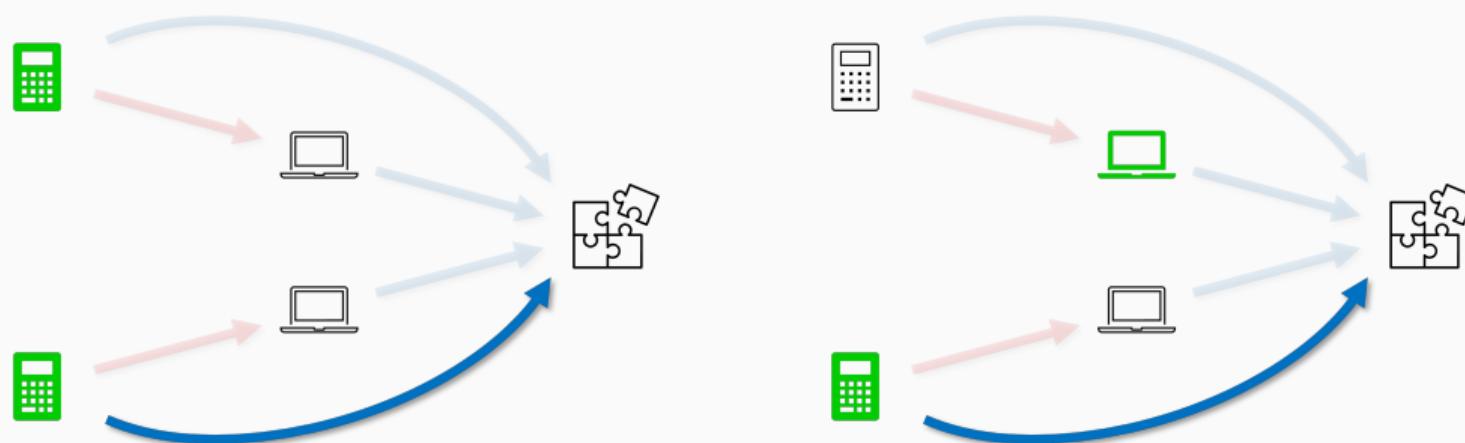
- Do research regardless of the rival's progress



## Benchmark Strategy 2: Direct-Development Strategy

### Direct-Development Strategy

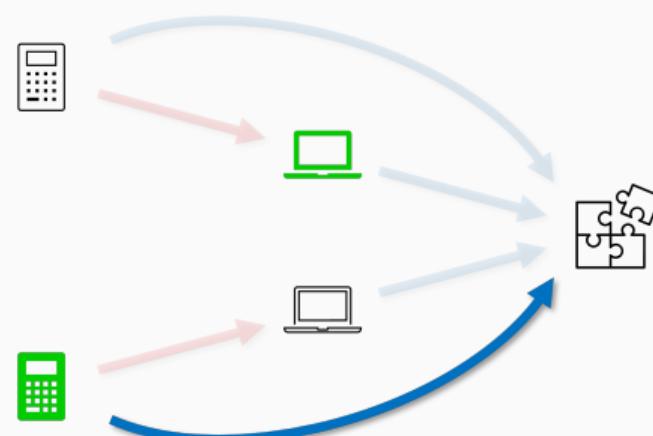
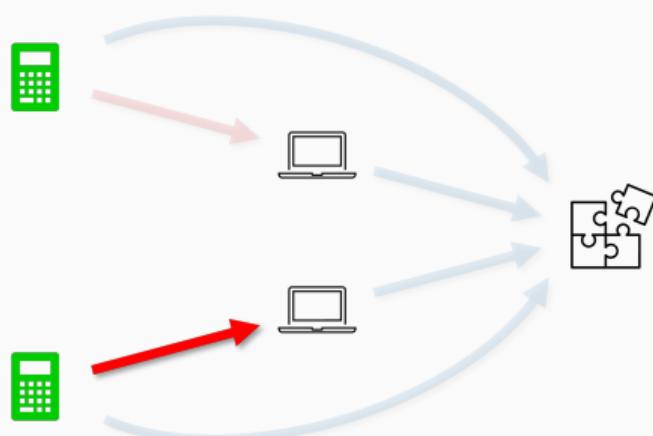
- Develop with the old technology regardless of the rival's progress



# 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

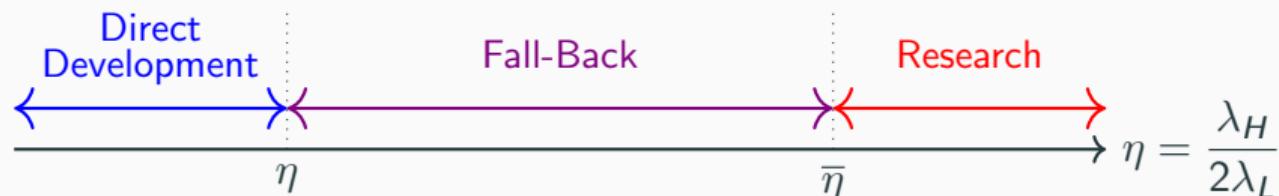


# Public Information: MPE Characterization

## Proposition 1

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

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



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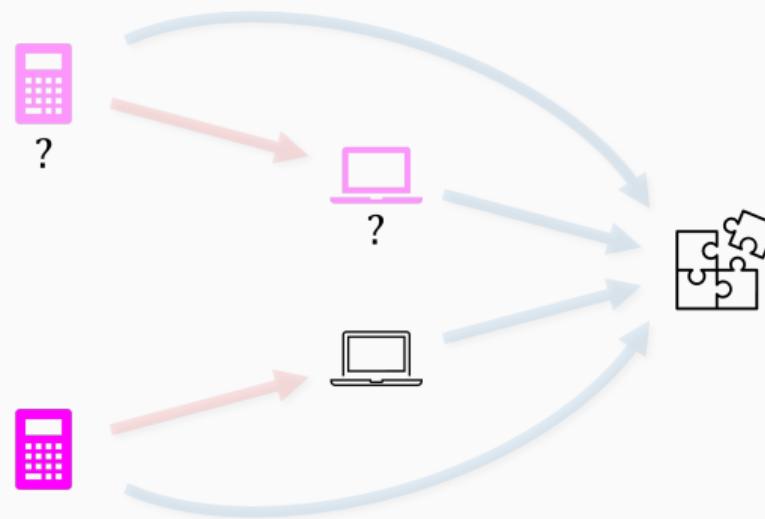
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## Private Information: Strategies

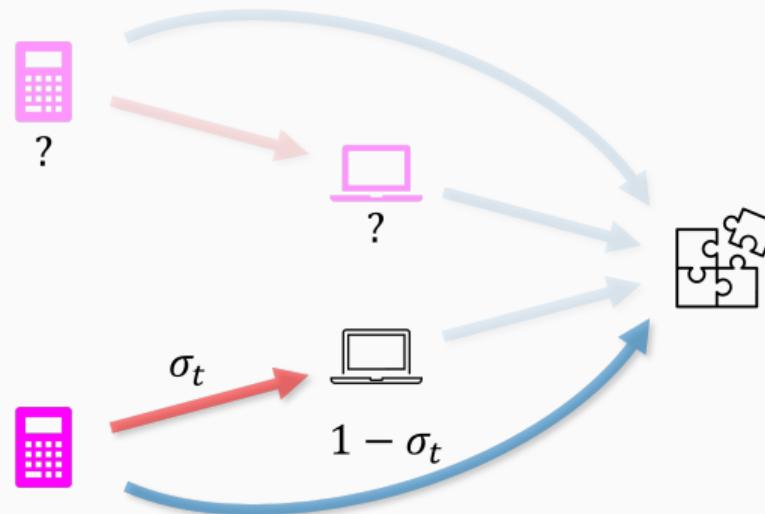
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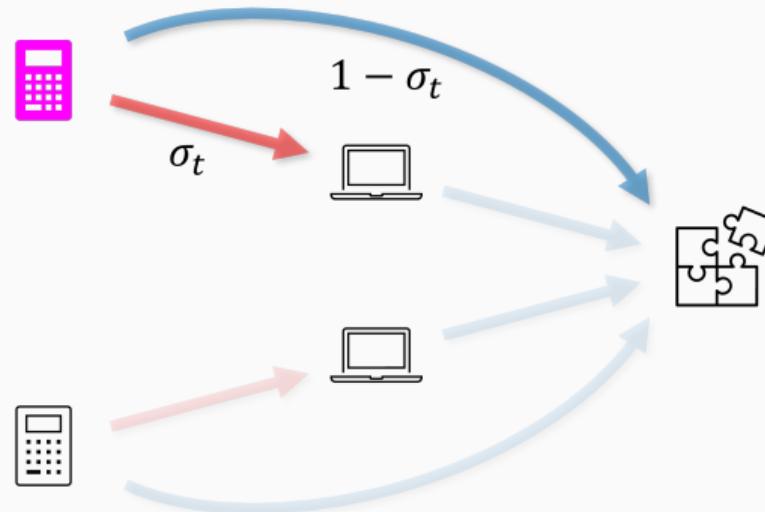


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# Private Information: Belief Updating

- Given the rival's strategy  $\sigma$ , the firm forms a belief  $p$

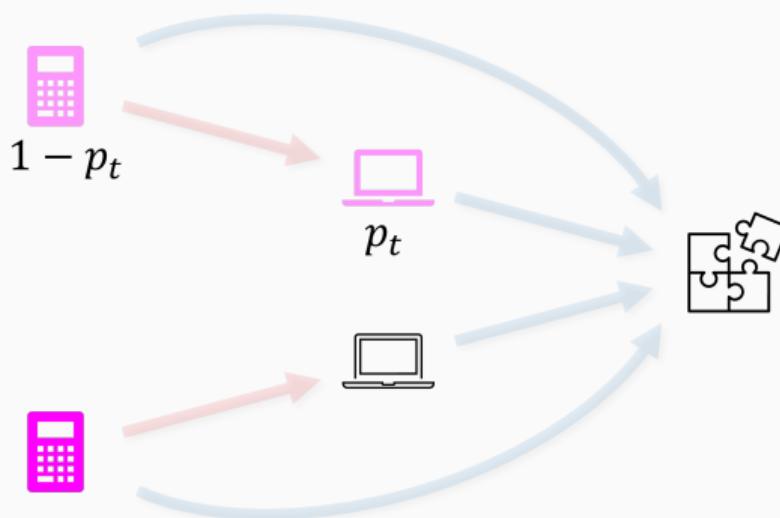
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## Private Information: Symmetric Markov Equilibrium

### Solution concept: Symmetric Markov Equilibrium (SME)

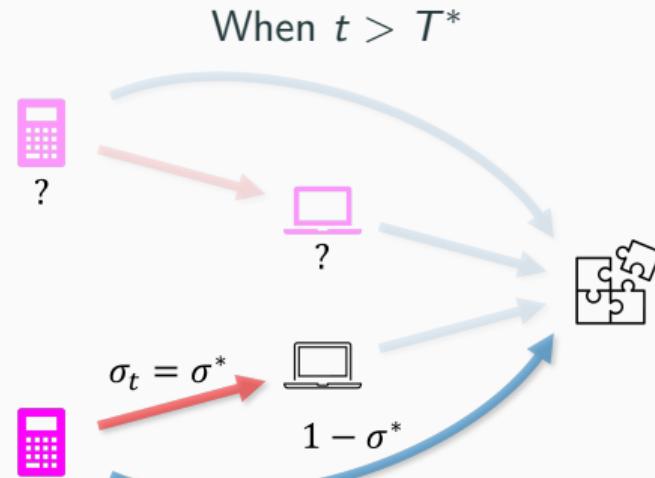
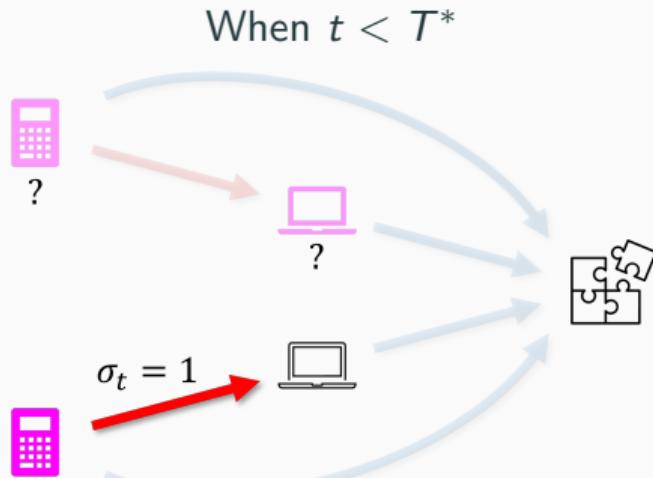
- $\sigma_t^A = \sigma_t^B = \sigma_t$  for all  $t \geq 0$ ;
- Sequential rationality
  - Given a strategy profile  $\sigma$ , the belief  $p_t$  is updated by Bayes' rule
  - At each point in time  $t$ ,  $\sigma_t$  maximizes the expected payoff in the continuation game
- $\sigma$  is a Markov strategy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

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

▶ HJB

# Stationary Fall-Back Strategy

- Fall-Back strategy is no longer feasible



# Private Information: Symmetric Markov Equilibrium

## 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

- the research strategy ( $T^* = \infty$ ) if  $\eta \geq \bar{\eta}$ ;
- the direct-development strategy ( $T^* = 0, \sigma^* = 0$ ) if  $\eta \leq \underline{\eta}$ ;
- the stationary fall-back strategy ( $T^* \in (0, \infty), \sigma^* \in (0, 1)$ ) if  $\eta \in (\underline{\eta}, \bar{\eta})$ .

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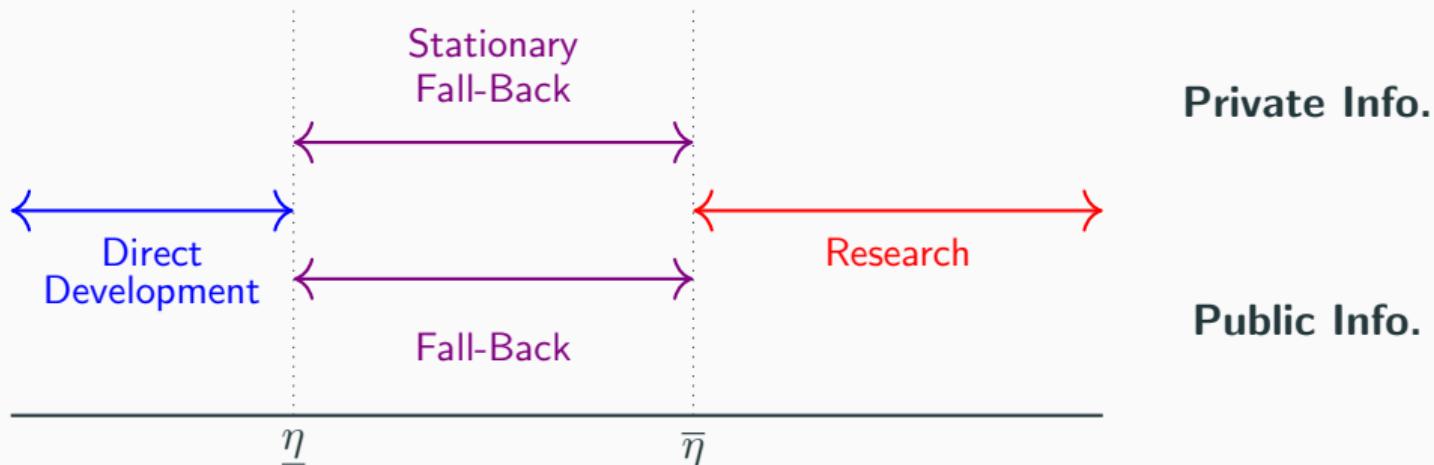
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# Private Information: Symmetric Markov Equilibrium



**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

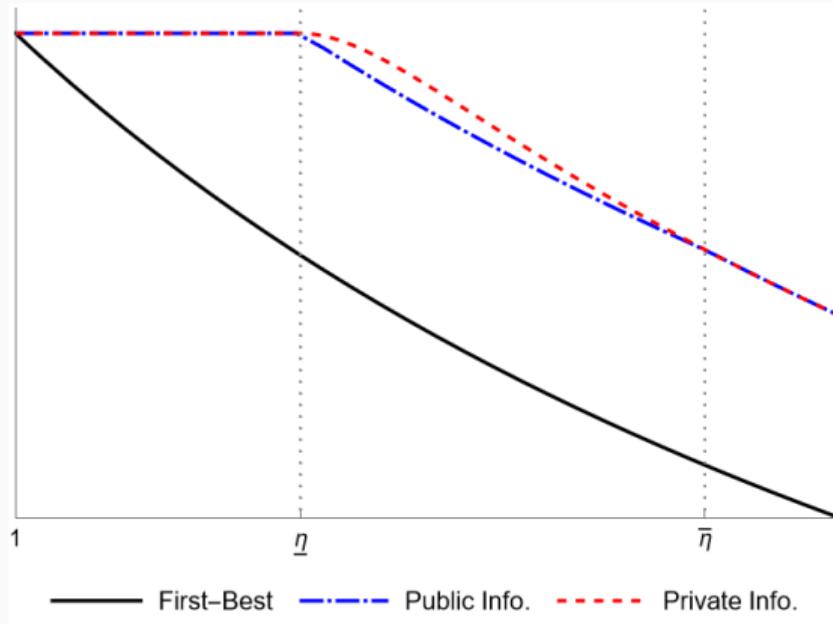
- When the fall-back strategy is not an MPE in the public information case, the observability does not affect the firms' resource allocations

## 2. Inside the fall-back region:

- when both firms keep doing research, as  $t \rightarrow \infty$ , the belief converges to 1
- firms *partially* switch to developing with the old technology when  $p$  is close to 1
- find  $p^*$  and  $\sigma^*$  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

1. Introduction

2. Model

3. Public Information Setting

4. Private Information Setting

5. Disclosure vs. Concealment

6. Related Literature and Conclusion

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

► Formal Definitions

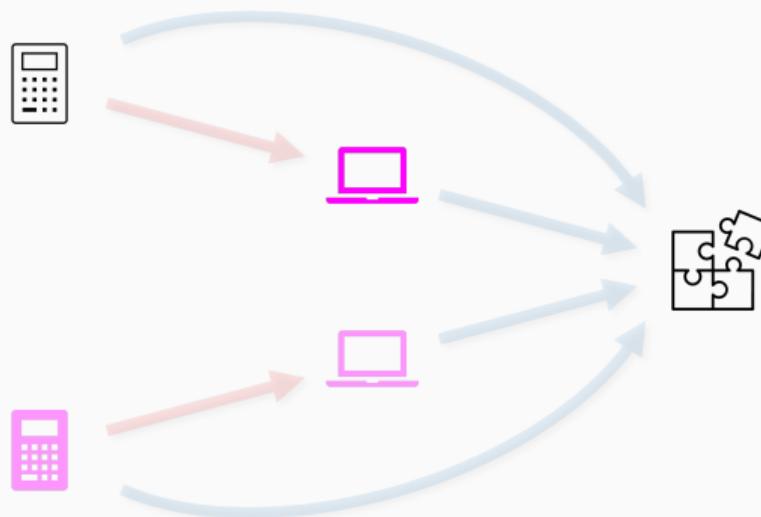
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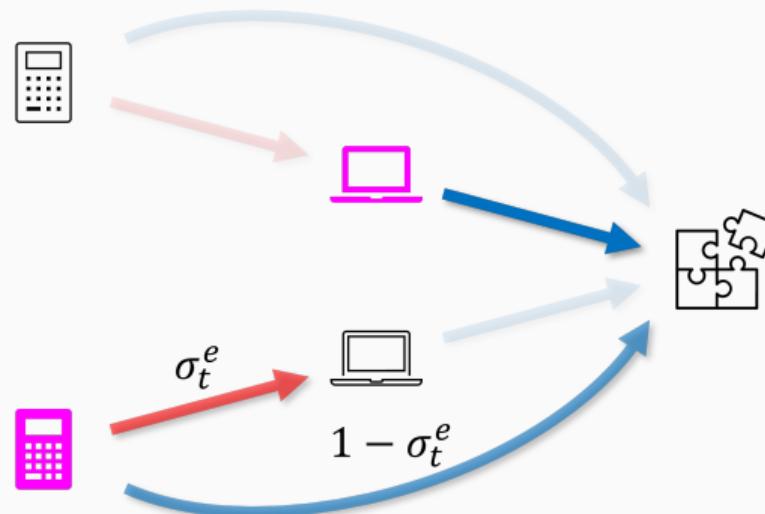
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- When a firm files a patent, it discloses the discovery of the new technology
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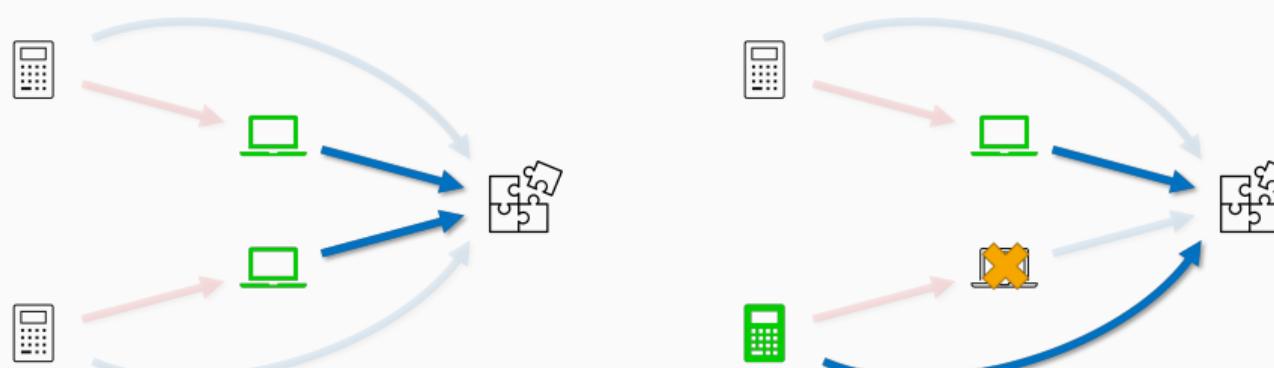
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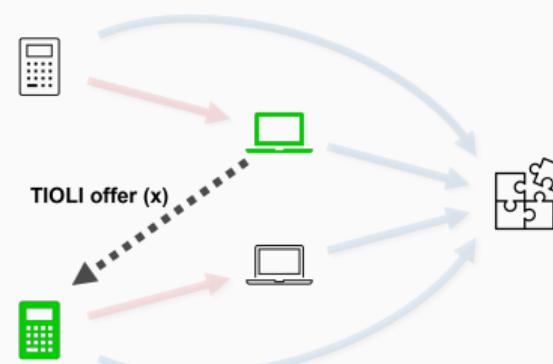
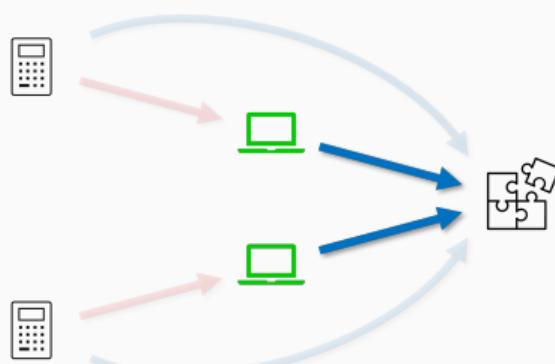
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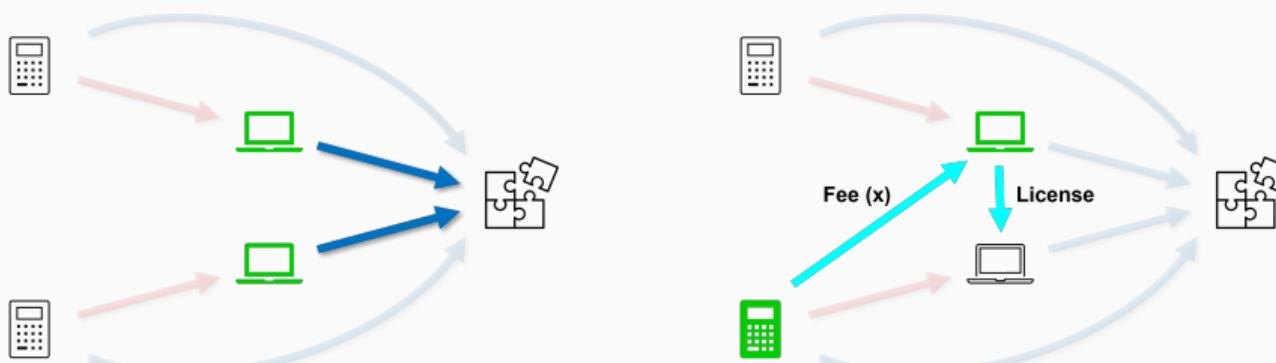
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## Disclosure vs. Concealment: Low Reward

### Proposition 3

Suppose that  $\eta \in (\underline{\eta}, \bar{\eta})$ . There exists  $\Pi_0$  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

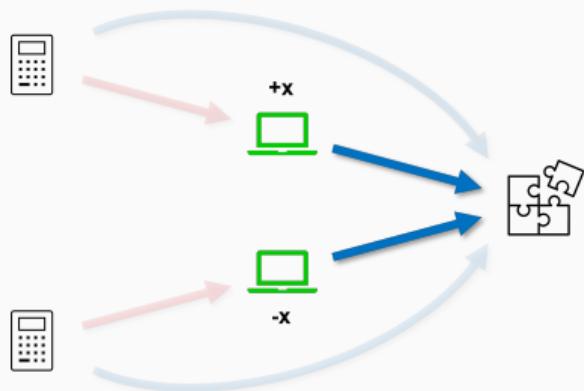
Suppose that  $\eta \in (\underline{\eta}, \bar{\eta})$ . There exists  $\Pi_1 \geq \Pi_0$  such that for all  $\Pi \geq \Pi_1$ , the *stationary-fall-back-and-no-disclosure* strategy constitutes an equilibrium:

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

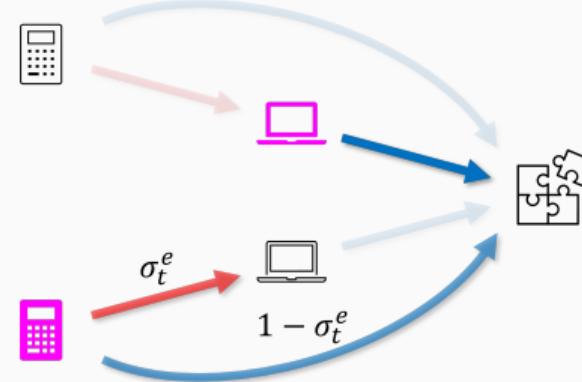
▶ Proof Sketch

# Disclosure vs. Concealment

## Patent (then License)



## Trade Secret



- Lower chance of winning the race
- Immediate license fee

- 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 ( $\Pi$ )
  - When  $\Pi$  is *small*, the new technology is licensed as soon as a firm discovers  
(Outcome is equivalent to the **First-Best** case)
  - When  $\Pi$  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  $\Pi$   
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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

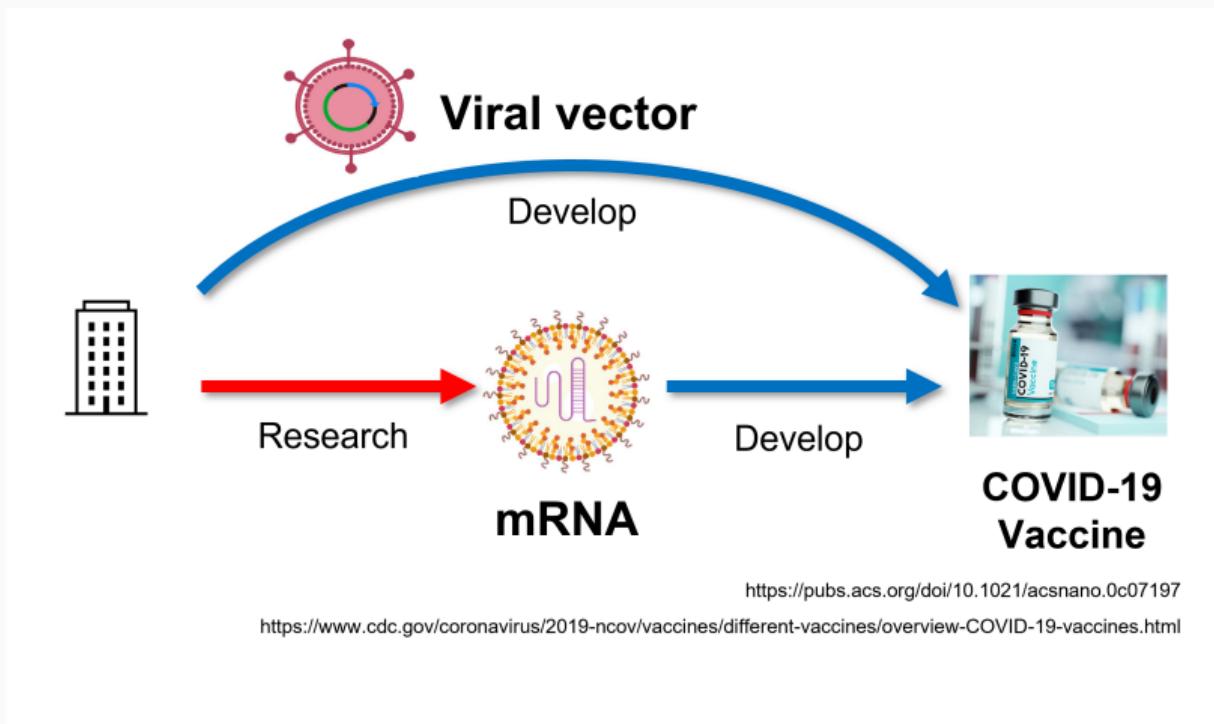
- We study firms' strategic incentives to conceal their interim technology
  - We introduce an innovation race model with multiple paths
  - We characterize the equilibrium behaviors of firms when their research progress is public or private information
  - Prize of winning the race ↑
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**Thank you!**

## Preview of Framework: Further Examples



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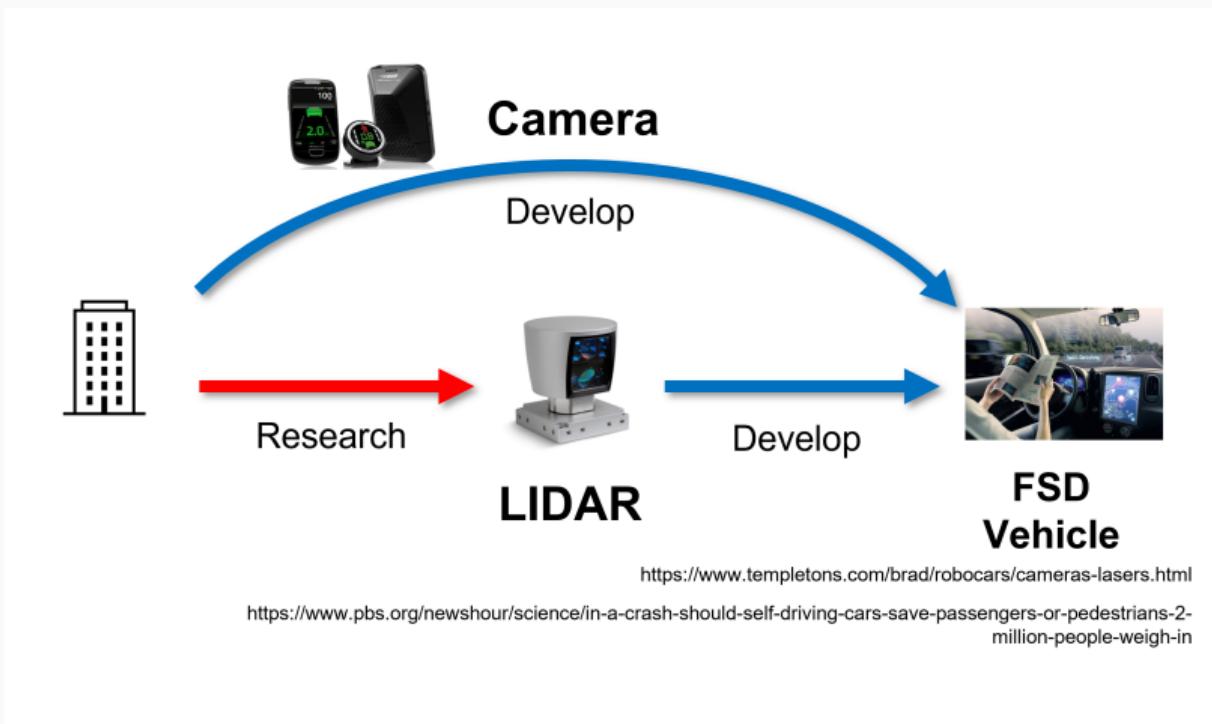


TABLE 3  
SUMMARY OF MAIN SURVEY RESULTS

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.

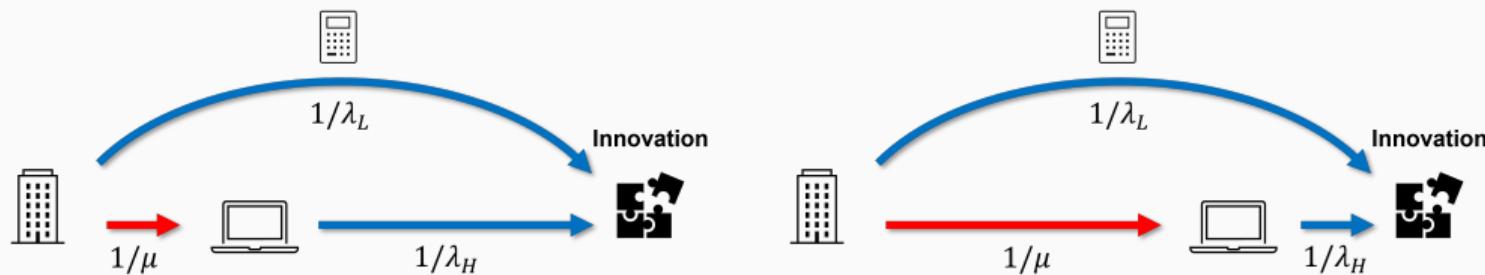
or

## 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)

## Model: Relative Intensity

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

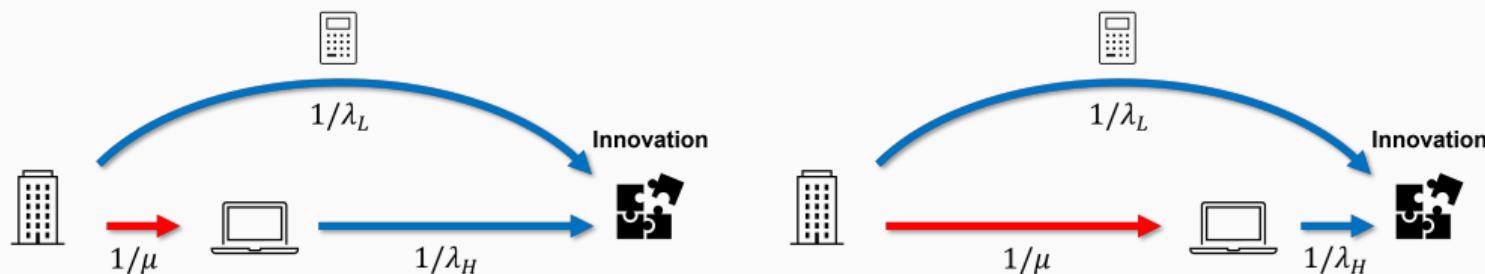


New technology is development intensive ( $\delta \downarrow$ )

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

## Model: Relative Intensity

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



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

## 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**

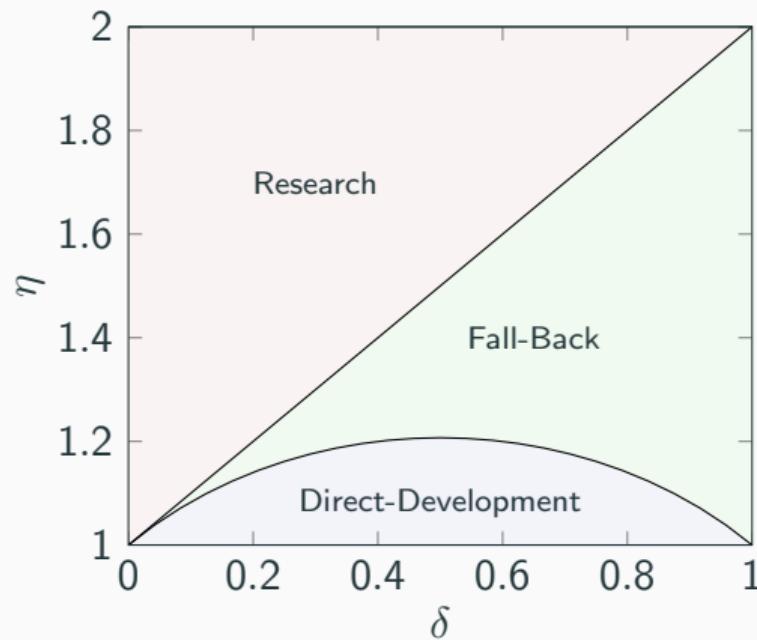
- *Research strategy* :  $\sigma_i(\emptyset) = \sigma_i(\{j\}) = 1.$
- *Direct-Development strategy* :  $\sigma_i(\emptyset) = \sigma_i(\{j\}) = 0.$
- *Fall-back strategy* :  $\sigma_i(\emptyset) = 1$  and  $\sigma_i(\{j\}) = 0.$

## Proposition

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

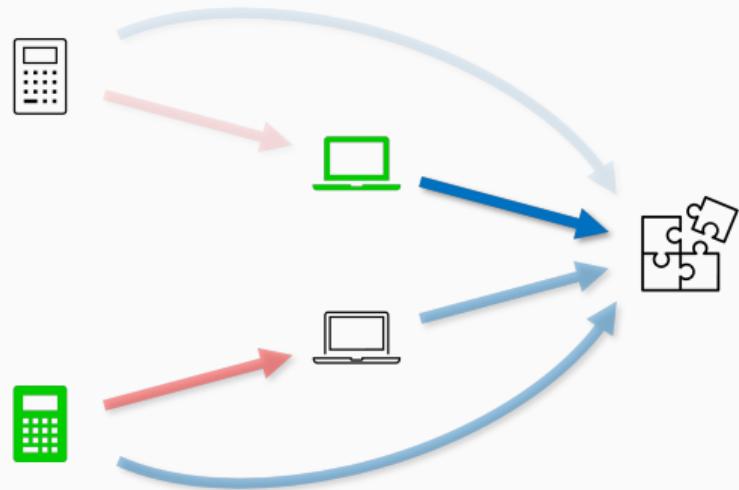
1. If  $\eta \geq \bar{\eta}(\delta) \equiv 1 + \delta$ , both firms play the research strategy;
2. If  $1 + \delta > \underline{\eta}(\delta) \equiv \frac{1}{2} \left( 1 + \sqrt{1 + 4\delta(1 - \delta)} \right)$ , both firms play the fall-back strategy;
3. If  $\underline{\eta}(\delta) \geq \eta$ ,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

## Public Information: MPE Illustration



**Figure 1:** MPE with observable technology.

# Public Information: Intuition for the Fall-Back Equilibrium

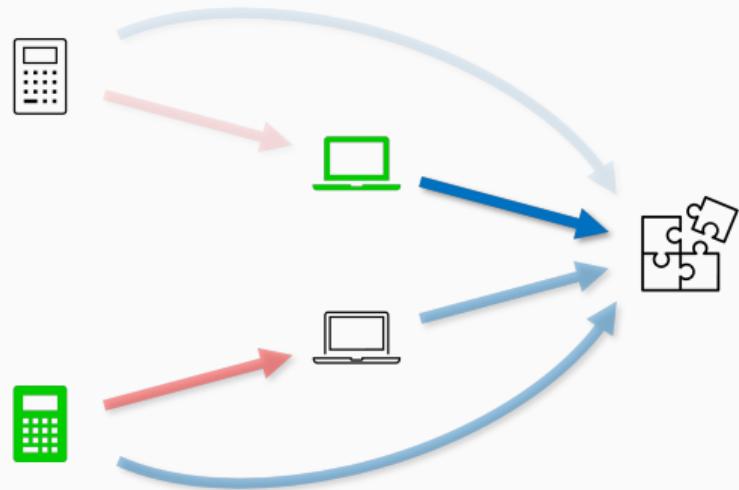


- Recall that development may be preferred over research in the short run when  $\eta$  is small ▶ SR Intuition
- Firm B knows that Firm A is likely to end the race soon  
⇒  $\exists \bar{\eta}$  such that the best response for Firm B is to:

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

▶ Go Back

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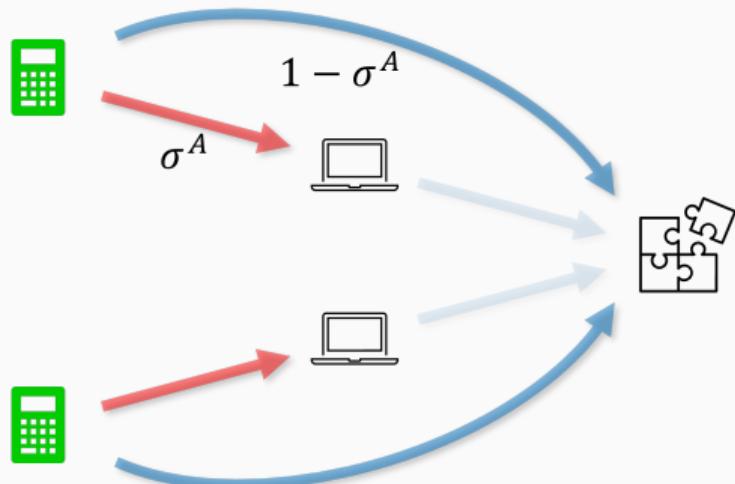


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▶ Go Back

## Public Information: Intuition for the Direct-Development Equilibrium



- There exists  $\underline{\eta} < \bar{\eta}$  such that the best response of Firm B for any given  $\sigma^A \in [0, 1]$  is to:  
$$\begin{cases} \text{do research,} & \text{if } \eta > \underline{\eta}, \\ \text{develop,} & \text{if } \eta < \underline{\eta}, \end{cases}$$

## 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  $\sigma^j$ ,  $p_t^i$  is characterized by the initial condition  $p_0^i = 0$  and

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

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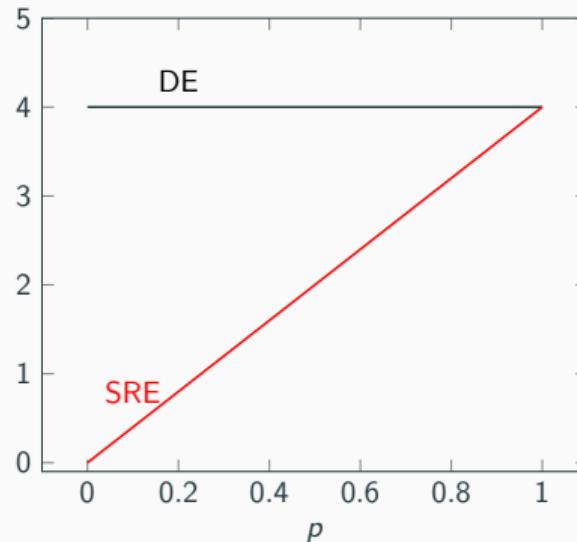
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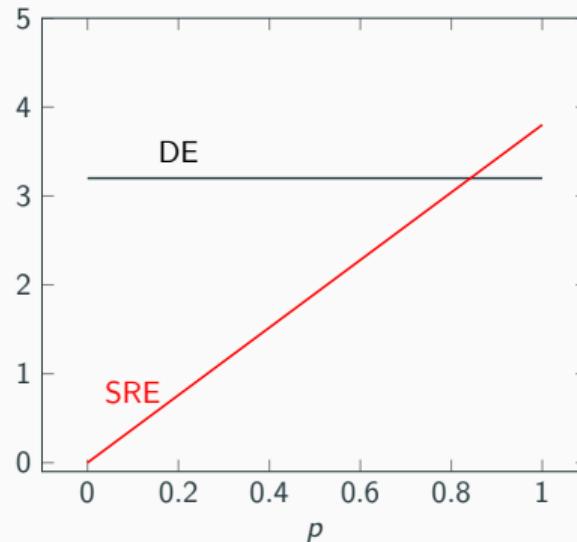
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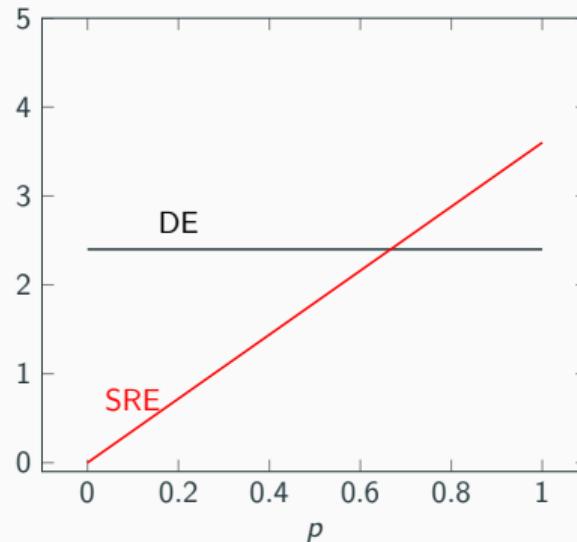
Duration Effect (Black) and Still-in-the-Race Effect (Red)  
for  $\sigma^j = 1$ ,  $\lambda_L = 1$ ,  $\mu = \lambda_H = 4$

## Private Information: Evolution of Beliefs



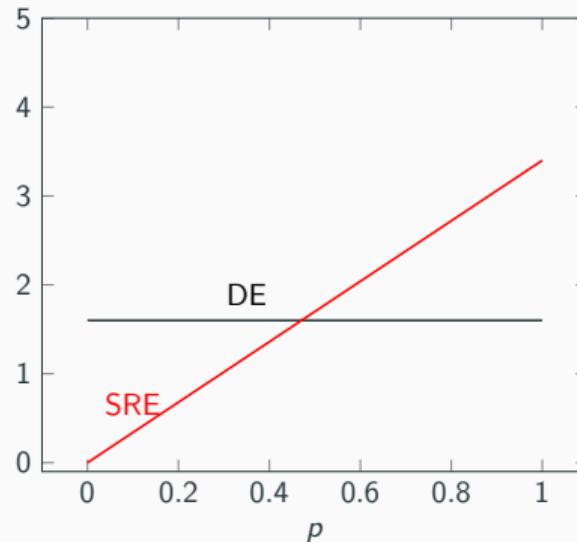
Mechanic Effect (Black) and Still-in-the-Race Effect (Red)  
for  $\sigma^j = .8$ ,  $\lambda_L = 1$ ,  $\mu = \lambda_H = 4$

## Private Information: Evolution of Beliefs



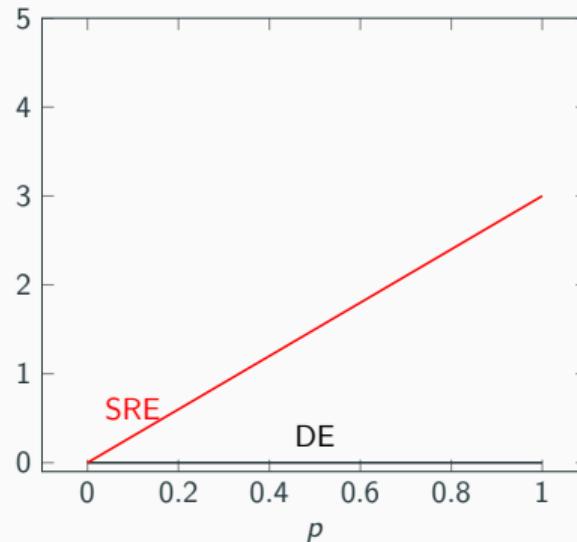
Mechanic Effect (Black) and Still-in-the-Race Effect (Red)  
for  $\sigma^j = .6$ ,  $\lambda_L = 1$ ,  $\mu = \lambda_H = 4$

## Private Information: Evolution of Beliefs



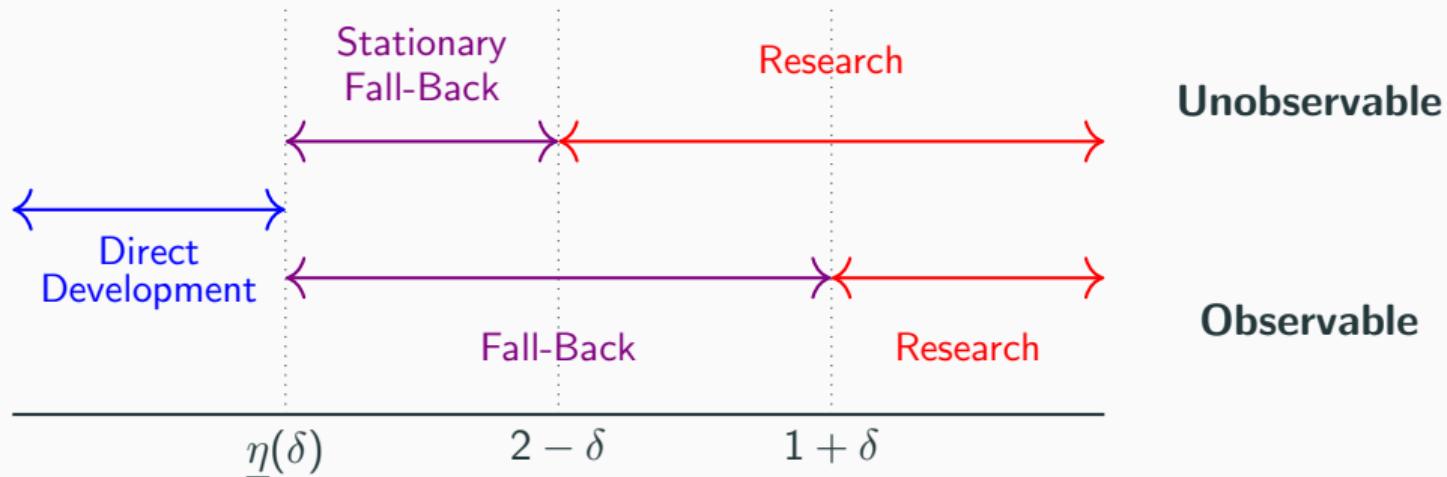
Mechanic Effect (Black) and Still-in-the-Race Effect (Red)  
for  $\sigma^j = .4$ ,  $\lambda_L = 1$ ,  $\mu = \lambda_H = 4$

## Private Information: Evolution of Beliefs



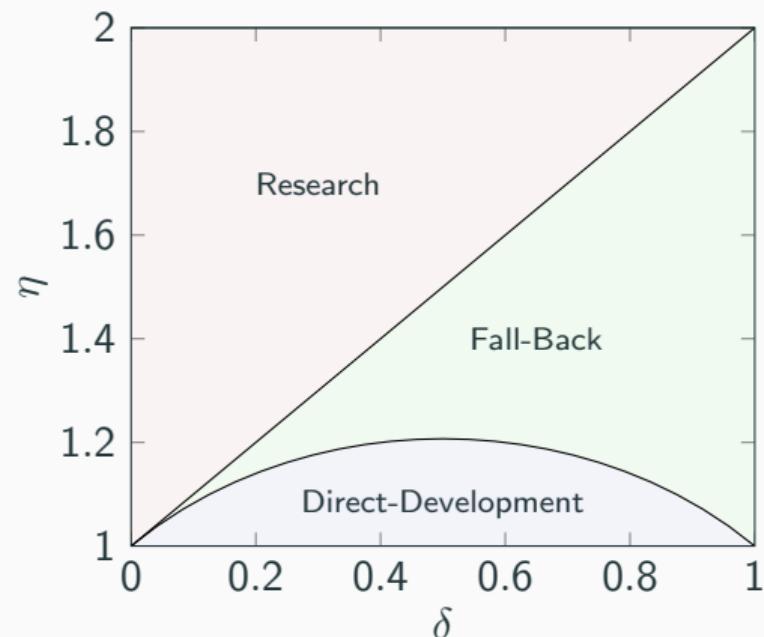
Mechanic Effect (Black) and Still-in-the-Race Effect (Red)  
for  $\sigma^j = 0$ ,  $\lambda_L = 1$ ,  $\mu = \lambda_H = 4$

# Private Information: Symmetric Markov Equilibrium

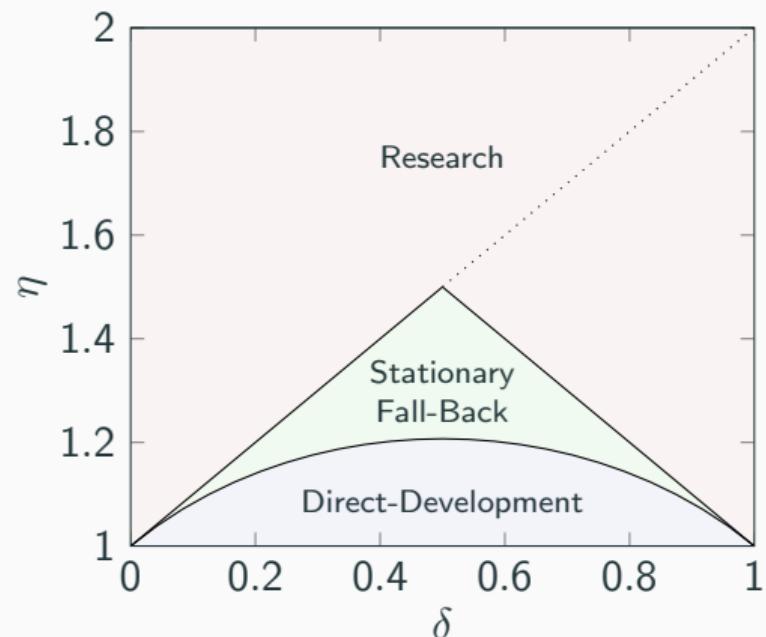


**Figure:** SME when  $\delta > 1/2$

# Private Information: Symmetric Markov Equilibrium



(a) Public Information Setting



(b) Private Information Setting

## 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

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

## Private Information: Proof Sketch

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

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

$\therefore$  (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  $\sigma$  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  $\sigma$  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  $\sigma^* = 0$ )
  - (b)  $\sigma_t > 0$  for all  $t \geq 0$  ( $T^* = \infty$ )

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$\therefore$  if  $p_t > 0$  and  $\sigma_t = 0$ ,  $\dot{p}_t < 0$
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6. Identify parametric regions where each strategy constitutes an SME

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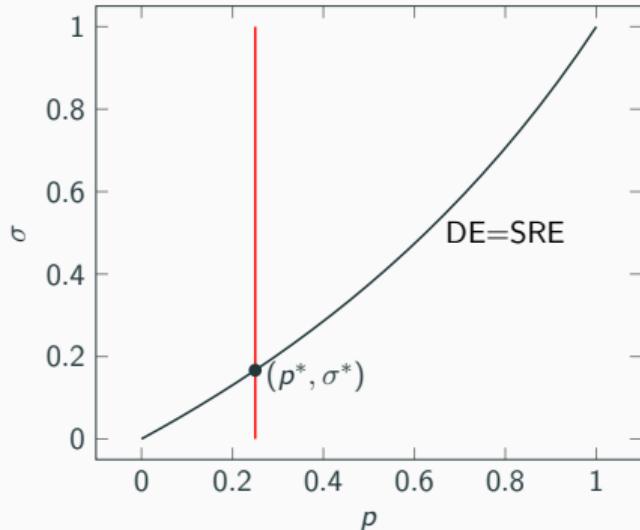
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Identifying  $(p^*, \sigma^*)$   
for  $\lambda_L = 2$ ,  $\mu = \lambda_H = 5$

- 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:

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

## 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  $H_t$

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

- $H_t : [t, \infty) \rightarrow [0, 1]$  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  $t' \geq t \geq 0$

- $(\lambda, T)$ -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  $\Pi$  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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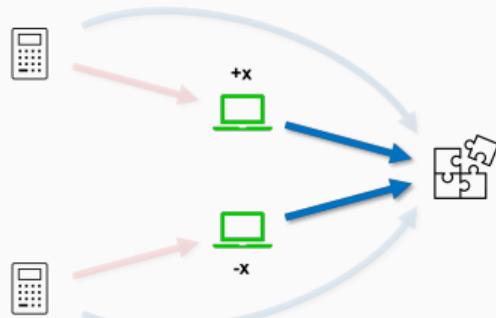
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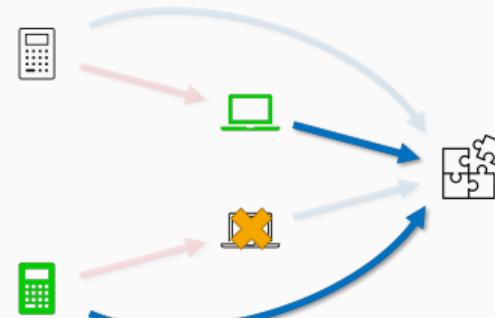
# Patent and License

Patent with Licensing (L)



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

Patent w/o Licensing (P)

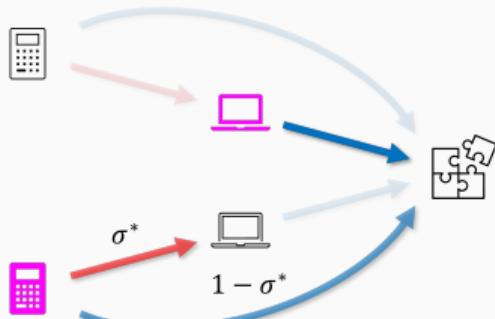


$$SW_P = \Pi - \frac{2c}{\lambda_H + \lambda_L}$$

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

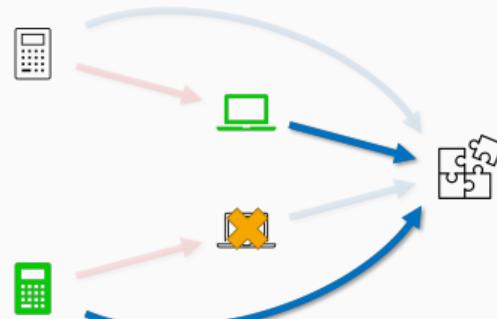
# Patent and Trade Secret

## 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 ( $\eta \in (\underline{\eta}, \bar{\eta})$ )

## 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  $\eta < \bar{\eta}$ .
- Therefore,  $V_S > V_P$  under  $\eta \in (\underline{\eta}, \bar{\eta})$ .