Strategic Concealment in Innovation Races

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Introduction

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- Multiple firms racing toward developing an innovative product
  - e.g., Software, COVID-19 vaccine, FSD vehicle
- Firms can *privately* discover interim knowledge that expedites the final innovation
  - e.g., new algorithm, mRNA technology, LIDAR technology
  - Firms can choose to disclose or conceal their discoveries
- **Q1**: How would *information* about interim discovery influence R&D dynamics?
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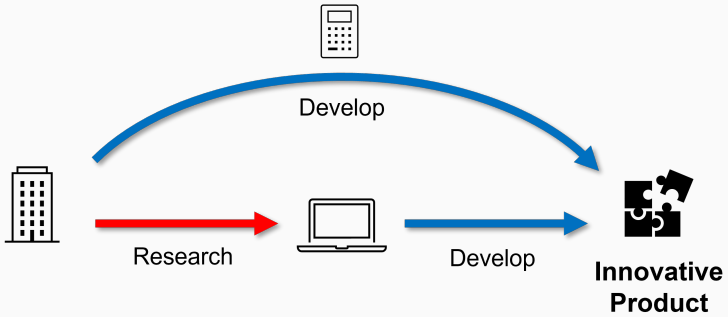
Preview of Framework

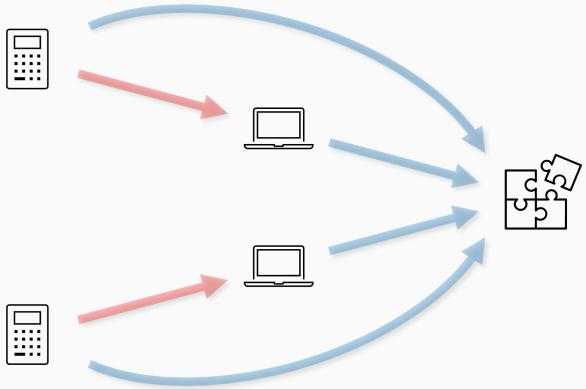
- Two paths toward the product development

▸ Further Examples



Preview of Settings

- There are two firms in the race



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Preview of Settings

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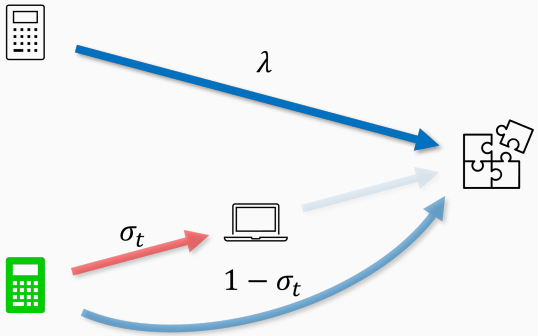
▸ Patent Game Tree

1. Benchmark: Constant Development Rate



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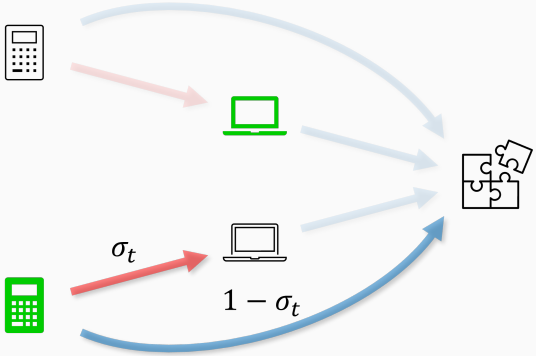

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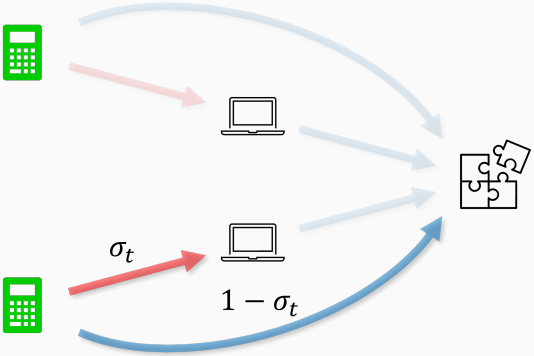

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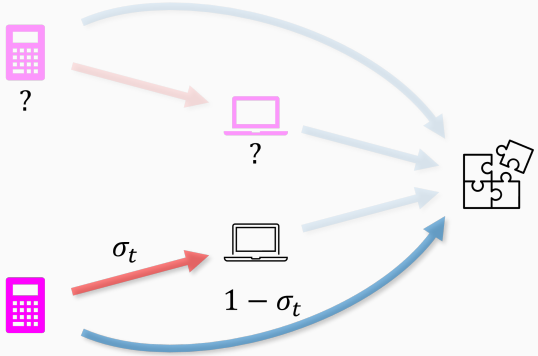

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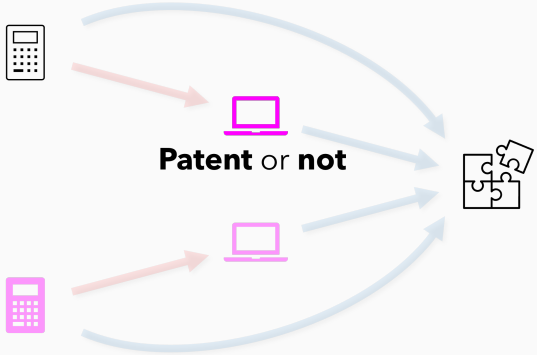

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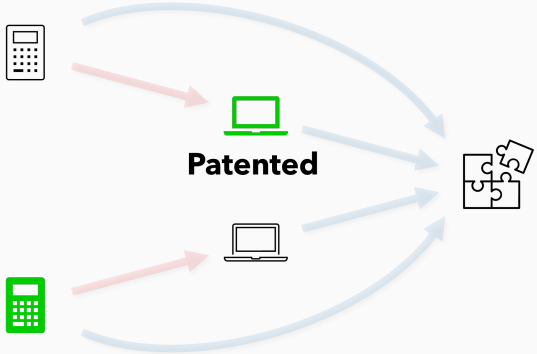

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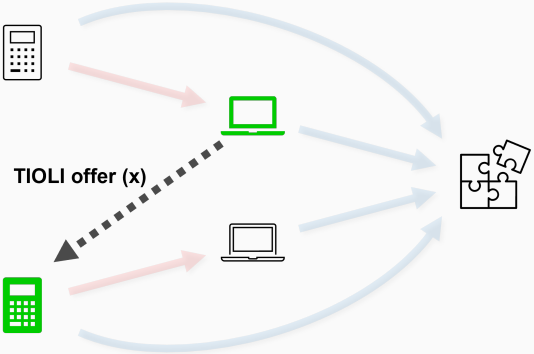

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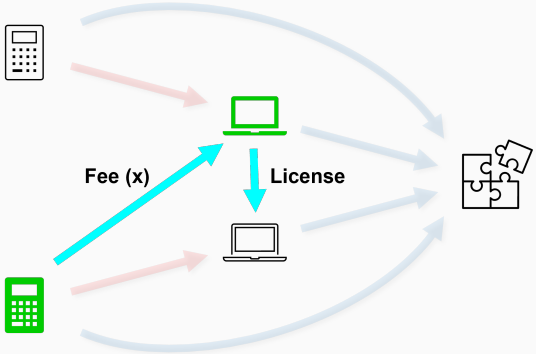

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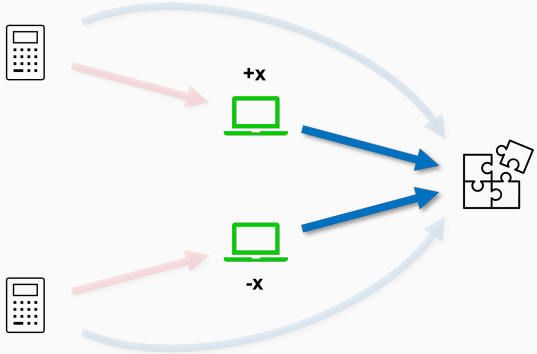

Preview of the Main Result

- **Tradeoffs**
  - *Patent* grants the right to use & license the new technology,
    but there is an informational disadvantage—the rival can adjust its R&D strategy
  - *Trade secret* has informational advantage,
    but a firm may face a risk of losing the property right

- **Main Results:** Firms' patenting decisions crucially depend on
  (i) the *trade secret protection level*; and (ii) the *reward* of winning the race
  - *High* protection & reward ⇒ firms **conceal** their discoveries ⇒ socially inefficient
  - *Low* protection or reward ⇒ firms file **patents** and **license** ⇒ socially desirable

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Model

Model: Preliminaries

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

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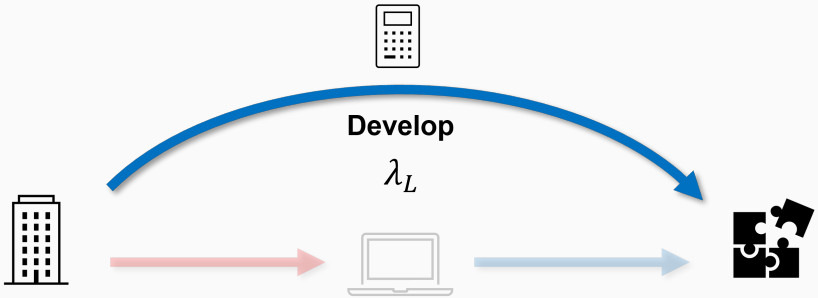

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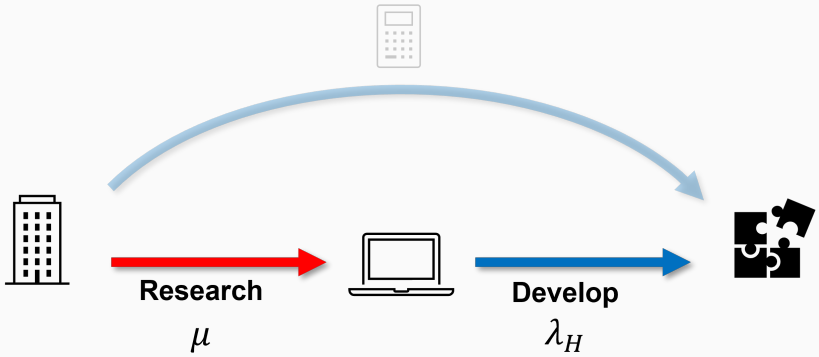

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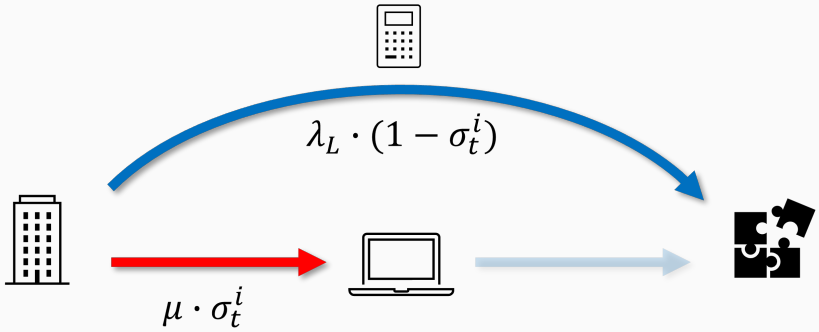

Partial Allocation

Model: Payoffs

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

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

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Model: Parametric Assumptions

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

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

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

2. Developing with the old technology is profitable:

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

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

▸ Low-Reward Case

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

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

Proposition 1

Suppose that Firm j's development rate is λ:

(a) if $\lambda < \lambda_\star$, Firm i conducts research;

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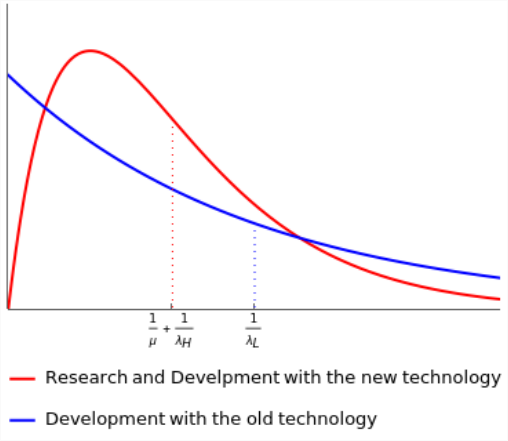

PDF of the completion time without race

Long Run:

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

Short Run:

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

Public Information Setting

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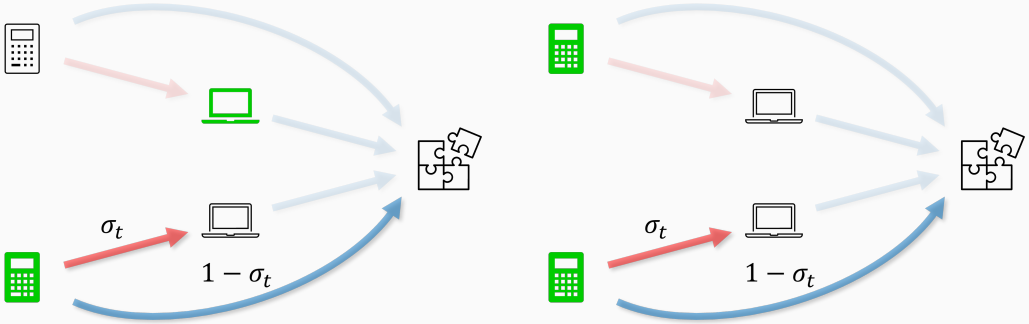
- **Strategy**: resource allocations over time contingent on the rival's status
- **Markov strategy**

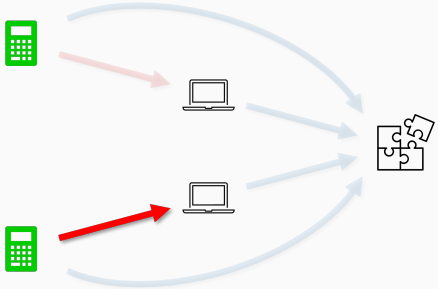
▸ Formal Definitions

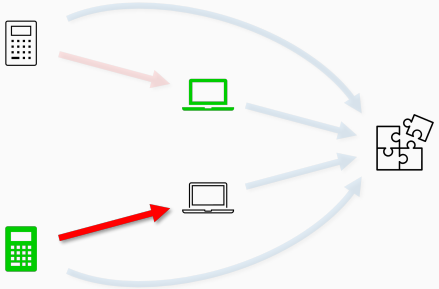
  - State variable: whether the rival has the new technology or not



Research Strategy

- Do research regardless of the rival's progress





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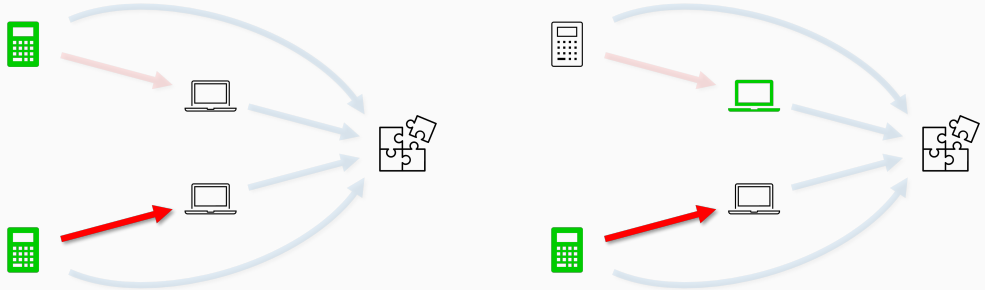

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Direct-Development Strategy

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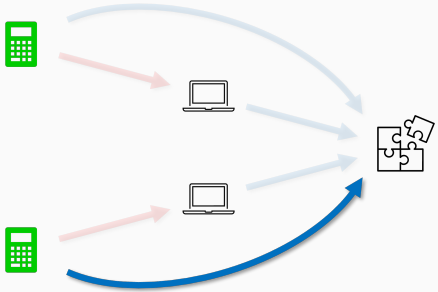

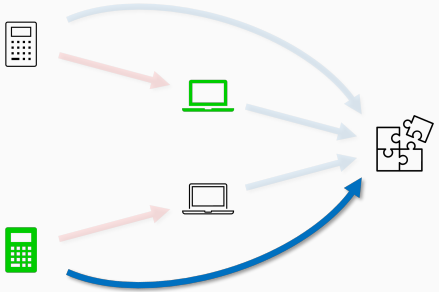

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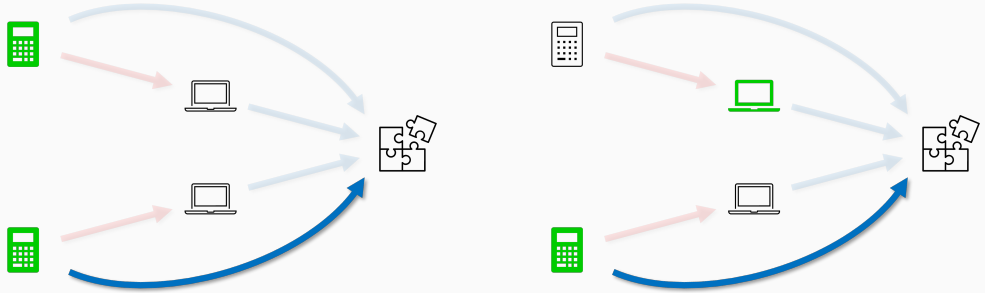

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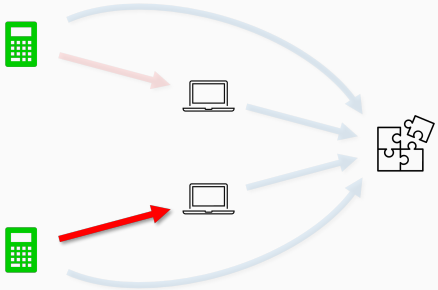
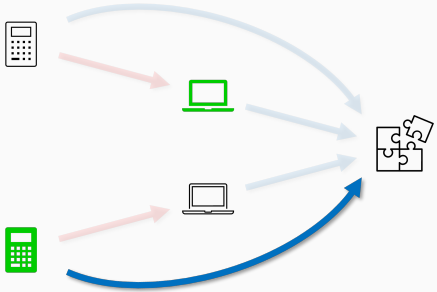
Fall-Back Strategy

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





Public Information: MPE Characterization

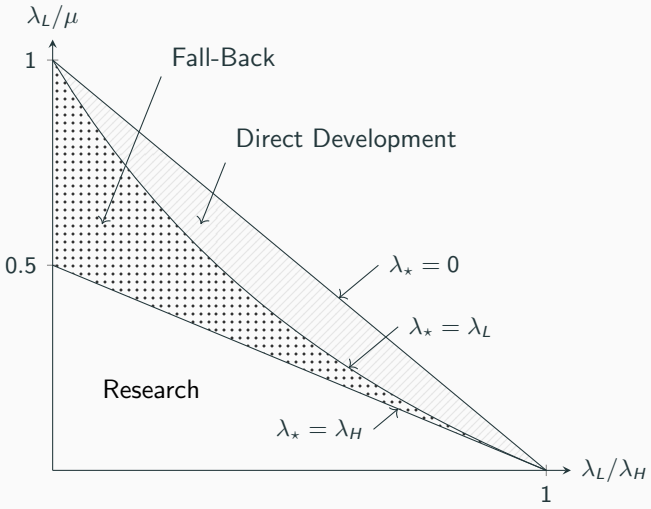
Theorem 1

Suppose that firms' research progress is public information. The *unique* Markov perfect equilibrium is characterized as follows:

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

- **Remark**: symmetry is obtained as a result

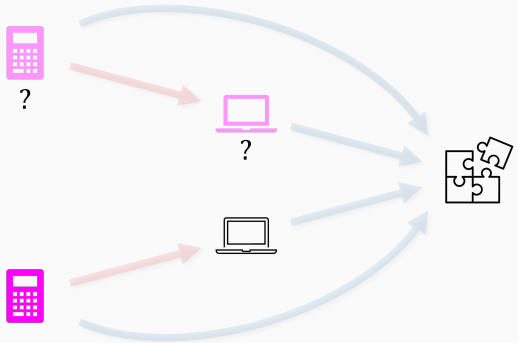
Public Information: MPE Characterization



Private Information Setting

Private Information: Strategies

- Firms cannot observe rivals' research progress



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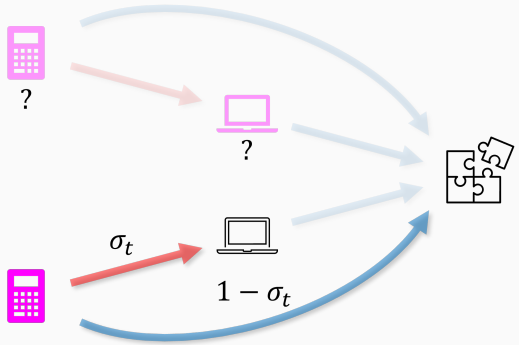

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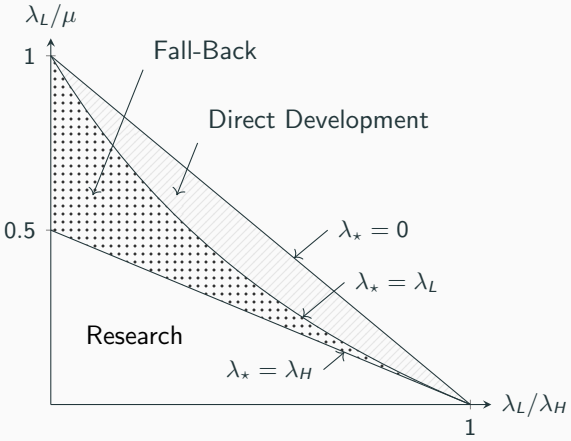
Public Information Results Revisited



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$\Rightarrow$ Same equilibrium under private information

What happens in the fall-back region?

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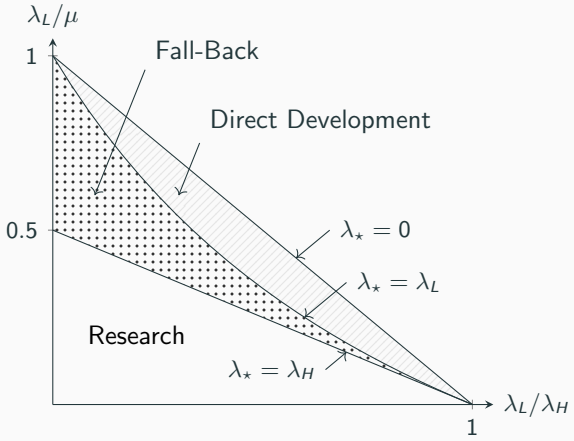

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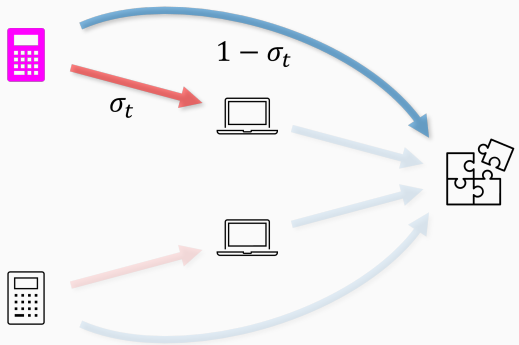
- Given the rival's strategy σ, the firm forms a belief p

▸ Belief Updating



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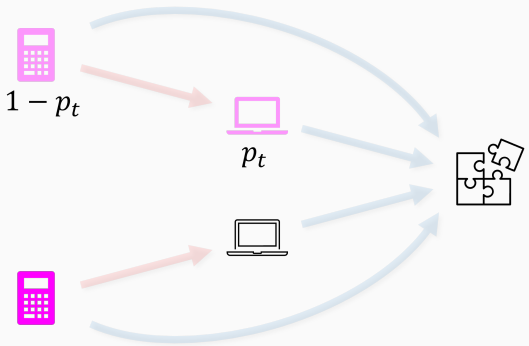

Private Information: Evolution of Beliefs

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

Lemma: Evolution of Beliefs

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

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

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

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

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

▸ Figures

Private Information: Evolution of Beliefs

Lemma: Evolution of Beliefs

Given Firm j conducts research,

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

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

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

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Private Information: Stationary Fall-Back Strategy

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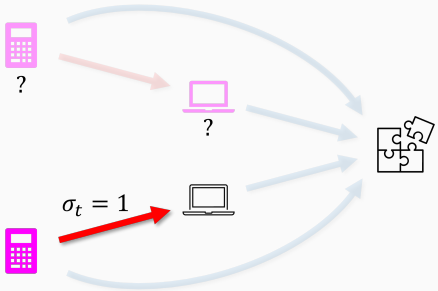

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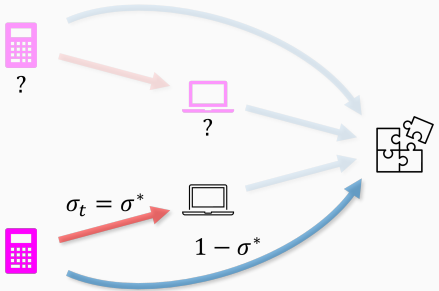

- In addition, $p_t = p^*$ for all $t \geq T^*$

Private Information: Equilibrium Characterization

Theorem 2

When firms' research progress is private information, there are three types of equilibria:

(i) if $\lambda_\star > \min\{\lambda_H, \mu\}$,
the research equilibrium ($\forall t,\ \sigma_t = 1$);

(ii) if $\lambda_\star < \lambda_L$
the direct-dev. equilibrium ($\forall t,\ \sigma_t = 0$);

(iii) if $\lambda_\star \in (\lambda_L, \min\{\lambda_H, \mu\})$,
the stationary fall-back equilibrium
($\exists T$ s.th. $\sigma_t = 1\ \forall t < T$ & $\sigma_t = \sigma_\star\ \forall t > T$)

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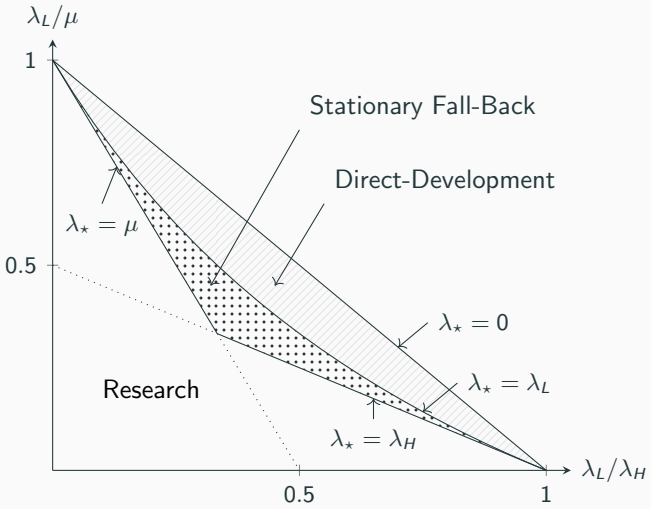

Patent, License and Trade Secret

Patent, License and Trade Secret

- Extend the model by allowing firms to patent & license the new technology

- Once a firm discovers the new technology, it can either
  1. apply for a patent (details will follow); or
  2. not apply for a patent—protects the new technology via *trade secret*

- Patent vs. Trade Secret
  - Patent applications are publicly available information
  - With trade secret protection, the information about the discovery is not released, but the firm may face a risk of losing the right to use the new technology
  - There is a trade secret protection level $\alpha \in [0, 1]$ (will be described soon)

▸ Additional Assumptions

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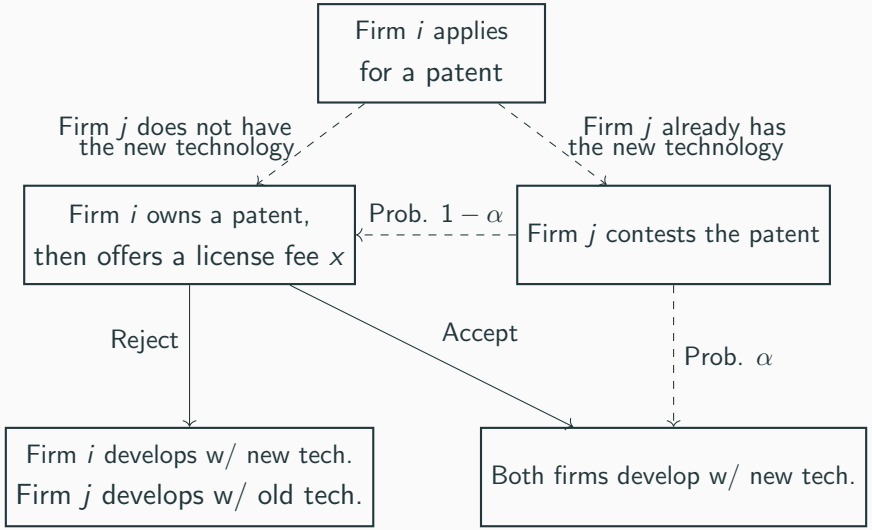
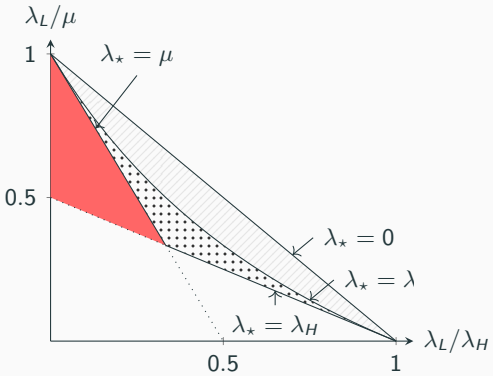

Firm i applies for a patent
Firm j does not have the new technology
Firm j already has the new technology
Firm i owns a patent, then offers a license fee x
Prob. $1-\alpha$
Firm j contests the patent
Reject
Accept
Prob. α
Firm i develops w/ new tech. Firm j develops w/ old tech.
Both firms develop w/ new tech.

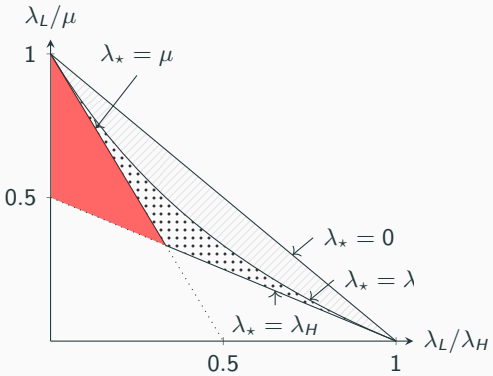
Go Back

Patent, License and Trade Secret: Equilibrium



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

Patent, License and Trade Secret: Equilibrium



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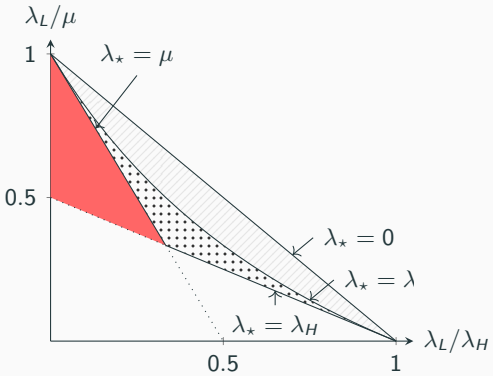

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There exists $\hat{\alpha}$ and $\hat{\Pi} : (\hat{\alpha}, 1] \to \mathbb{R}_+$ such that the efficient patent equilibrium exists if and only if (i) $\alpha \leq \hat{\alpha}$; or (ii) $\alpha > \hat{\alpha}$ and $\hat{\Pi}(\alpha) > \Pi$.

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- Why does Π matter?
  - Patent $\to$ information revealed $\to$ rival's outside option changes
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  - When Π is high, a firm may want the rival *squander* its time in research

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Patent, License and Trade Secret: Takeaways

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

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Related Literature and Conclusion

Literature on Patent vs. Secrecy

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

▸ Related Literature

Conclusion

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

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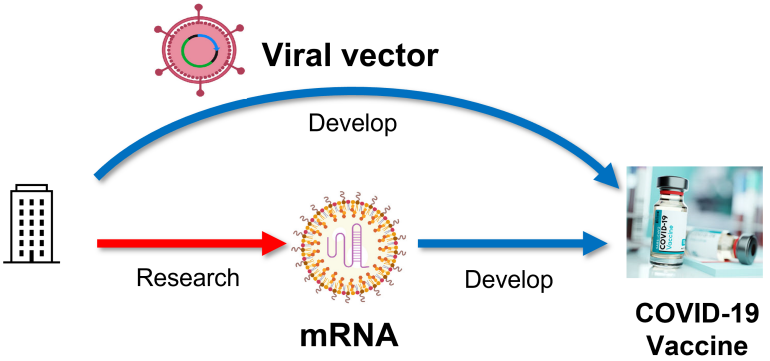
Thank you!

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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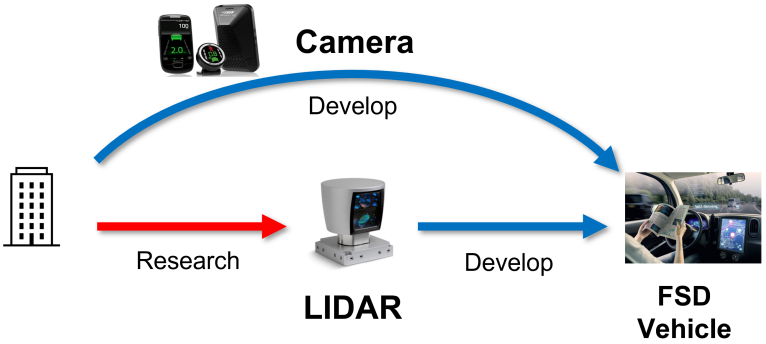

https://www.templetons.com/brad/robocars/cameras-lasers.html

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

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.

Go Back

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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First-Best Problem

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

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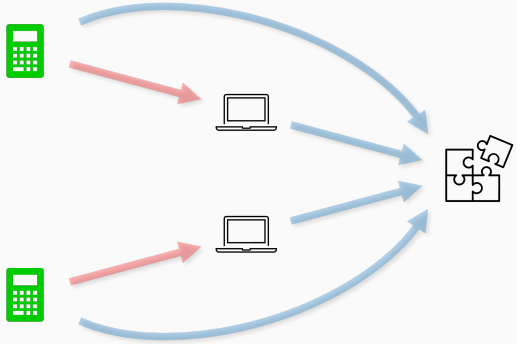

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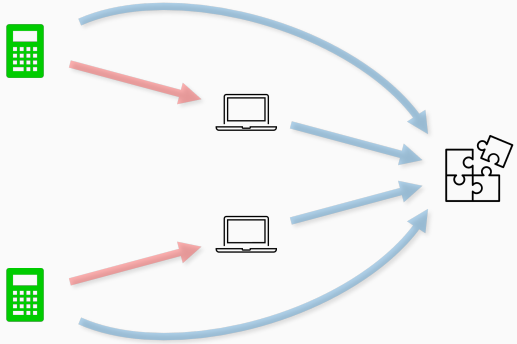

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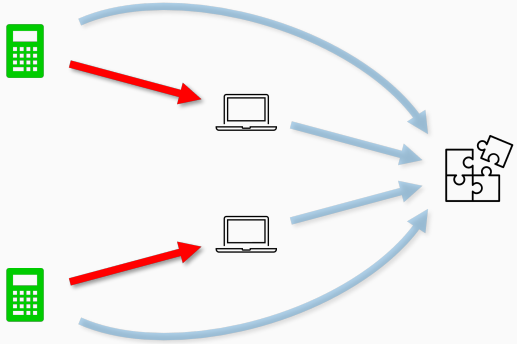

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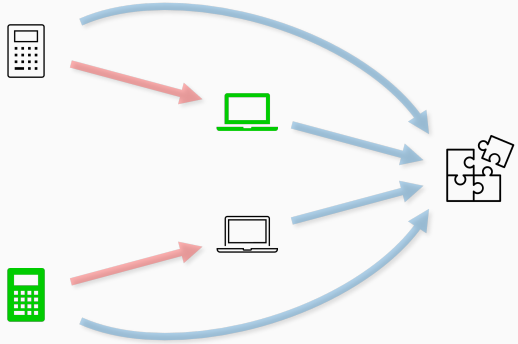

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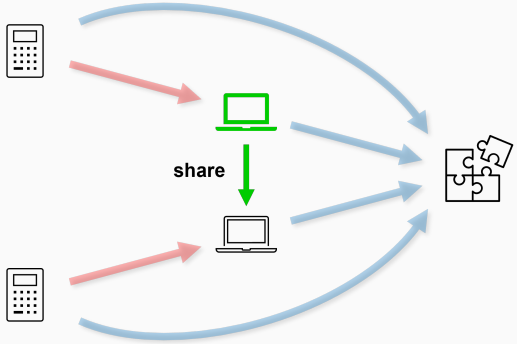

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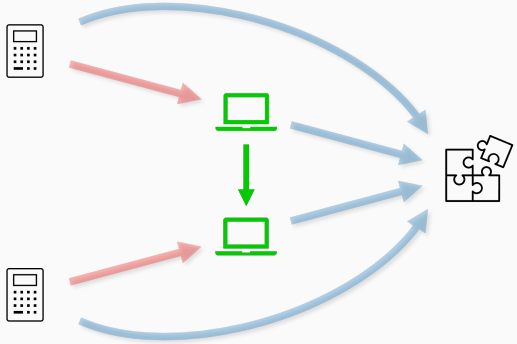

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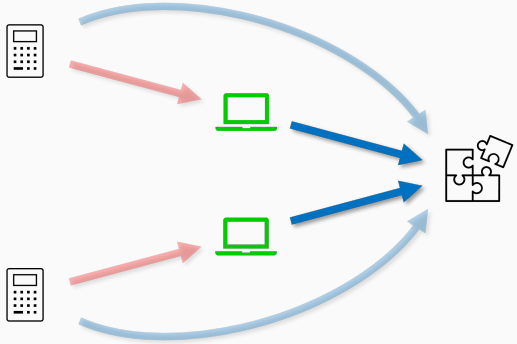
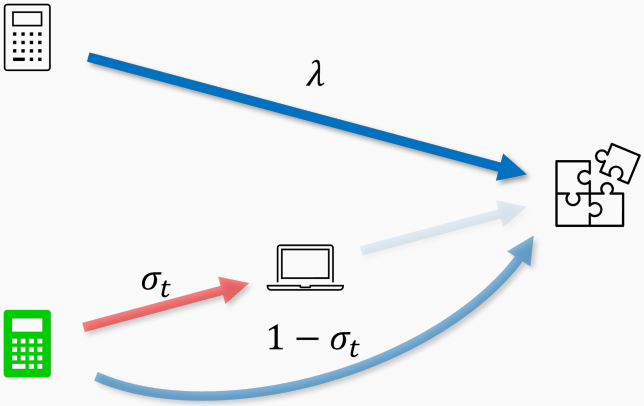


Benchmark: Constant Development Rate



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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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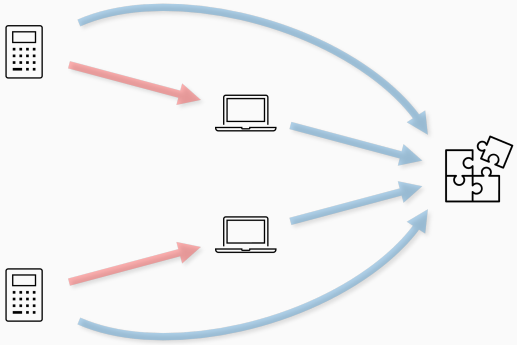
Patent, License, Trade Secret: Additional Assumptions

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

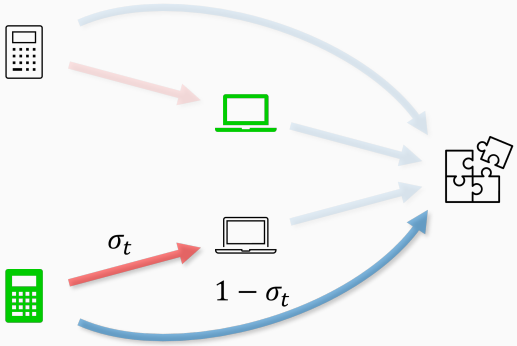
Go Back

Preview of Settings and Results



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

Preview of Settings and Results



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

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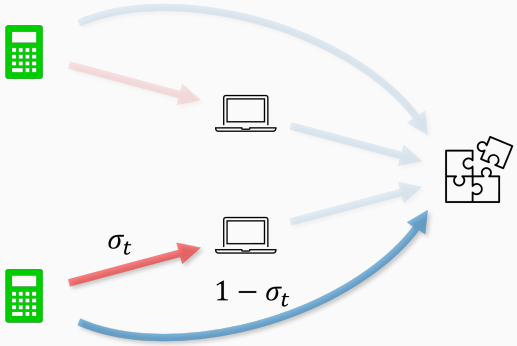

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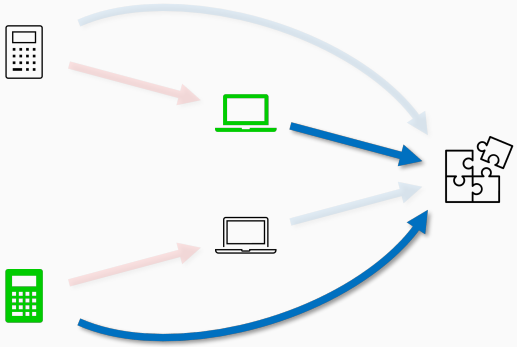

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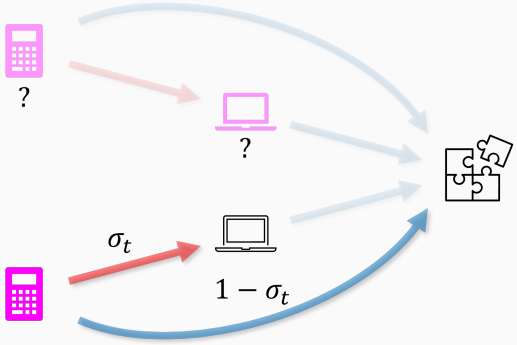

2. Private Information Setting

- Firms cannot observe each others' research progress
- How would firms allocate their resources to research and development over time?
- **Theorem 2:** $\exists\ T \in [0,\infty]$ and $\sigma_\star \in [0,1]$ s.th.

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

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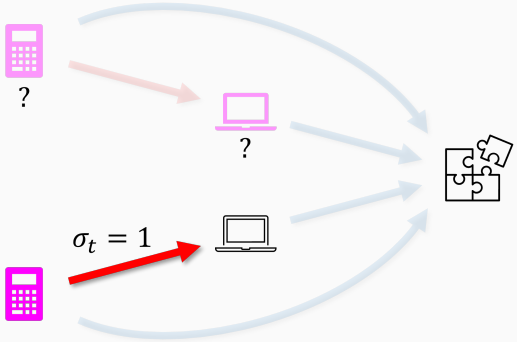

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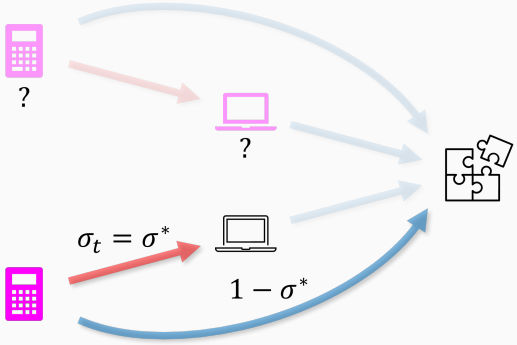

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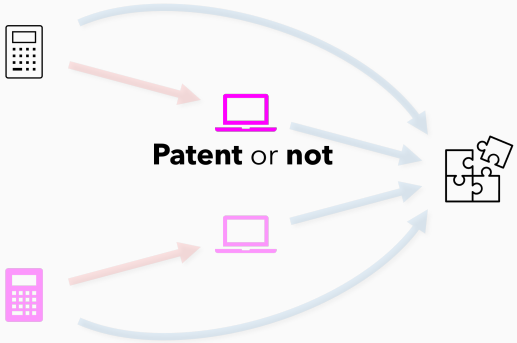

3. Patent Game
   - Extend the model by allowing firms to choose whether to apply for a patent or not (protect by trade secret)
   - Once patented, the firm offers a license offer to the rival firm

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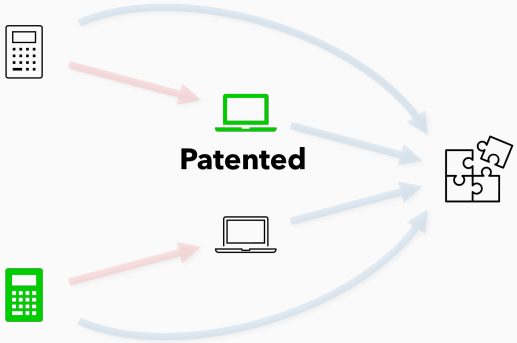

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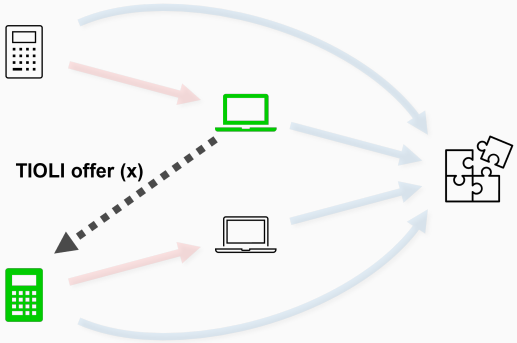

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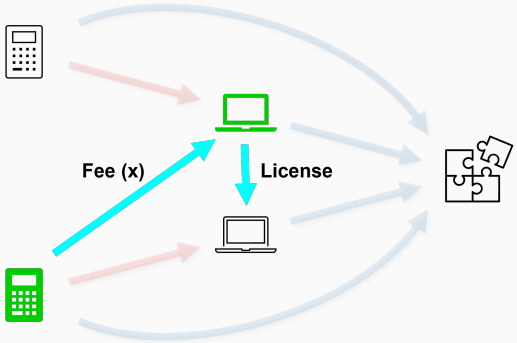

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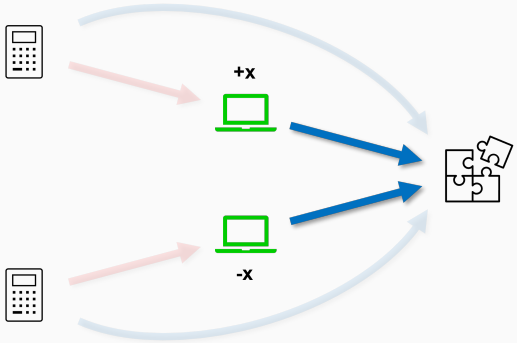

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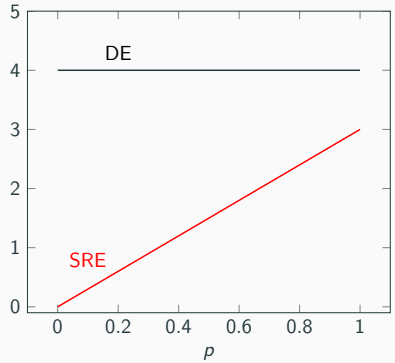
Private Information: Evolution of Beliefs



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

Go Back

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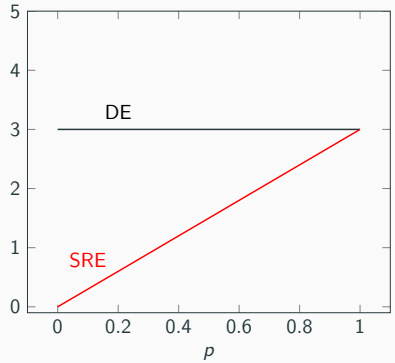

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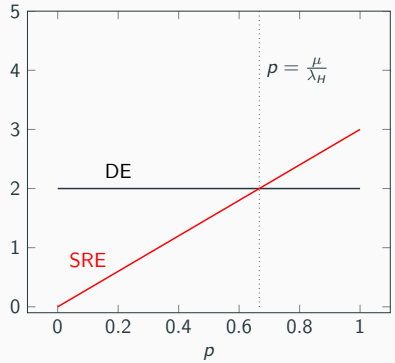
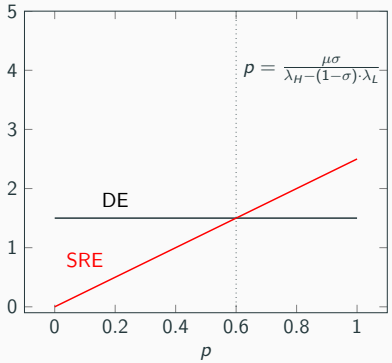


Duration Effect (Black) and Still-in-the-Race Effect (Red)
for $\sigma^j = 1$, $\lambda_L = 1$, $\mu = 2 < \lambda_H = 3$

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

Go Back

Private Information: Evolution of Beliefs



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

Go Back

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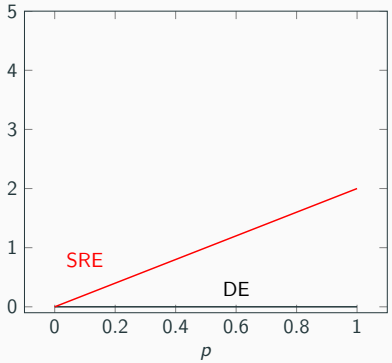

Duration Effect (Black) and Still-in-the-Race Effect (Red)
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Go Back

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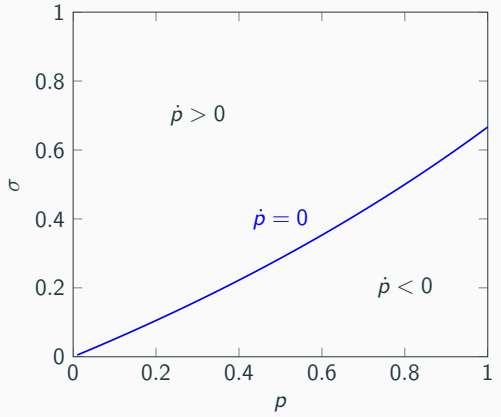
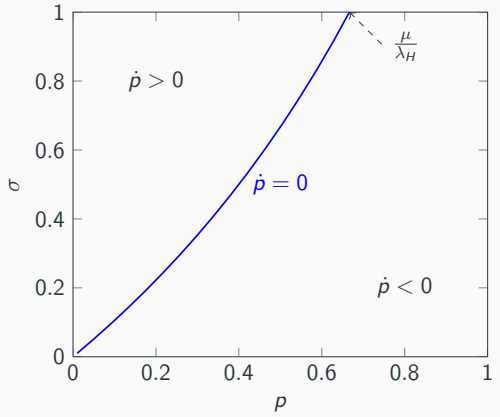


(a) $\mu > \lambda_H$



(b) $\mu < \lambda_H$

Private Information: Equilibrium Concept

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

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

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

HJB

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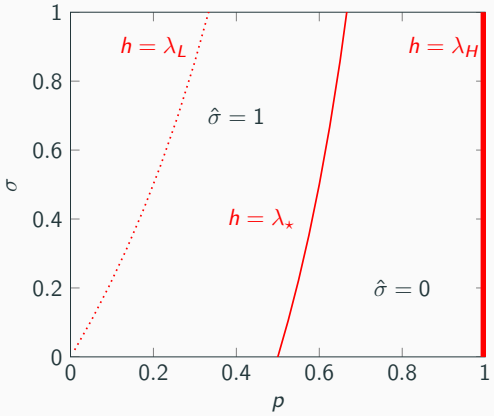
Private Information: Iso-development-rate Curve and Best Responses

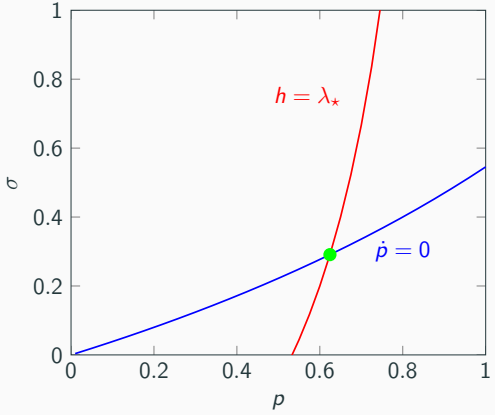


Iso-development curve and the best response when $\lambda_\star \in (\lambda_L, \lambda_H)$

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

▸ Proposition 1

Private Information: Steady State



$\mu > \lambda_H$ and $\lambda_H > \lambda_\star > \lambda_L$

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

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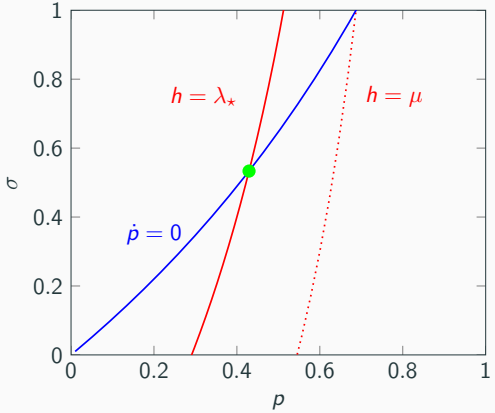

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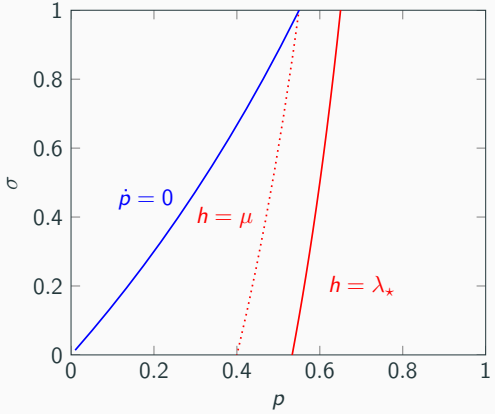

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Patent, License and Trade Secret

- When a firm applies for a patent, it discloses the discovery of the new tech.
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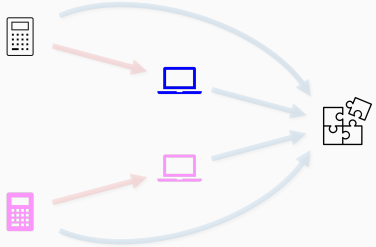
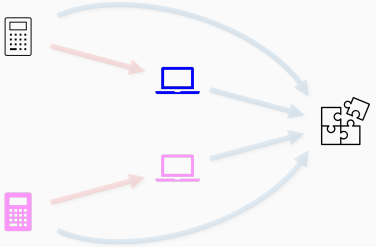
- The patenting firm makes a TIOLI license offer





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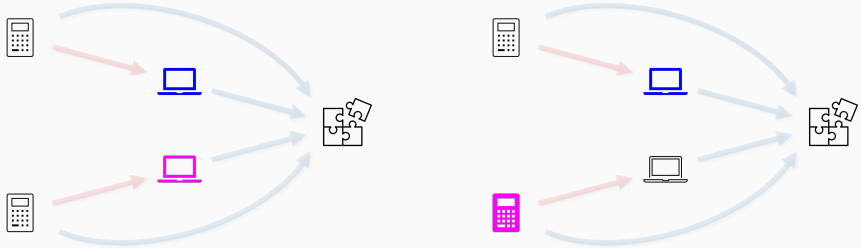

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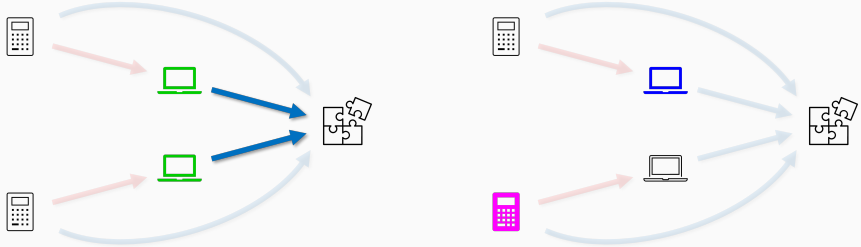

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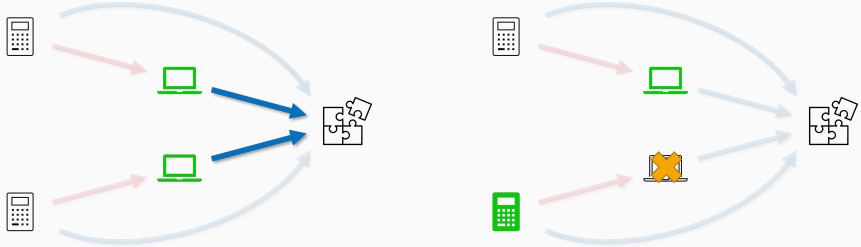

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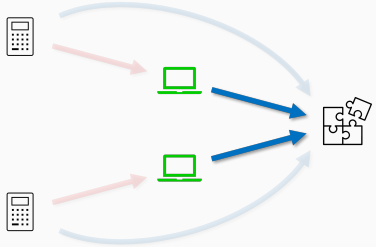

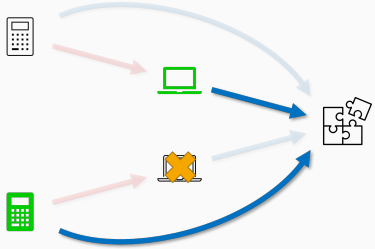

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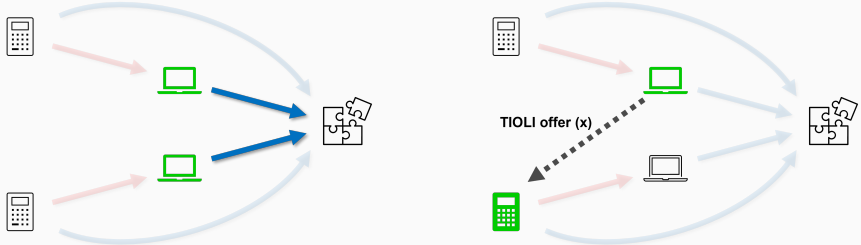

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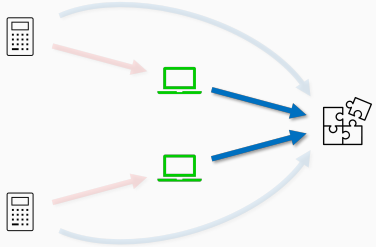
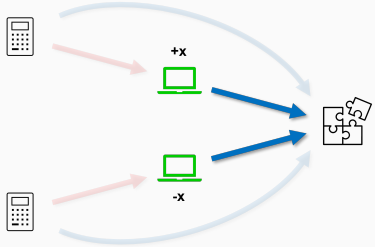


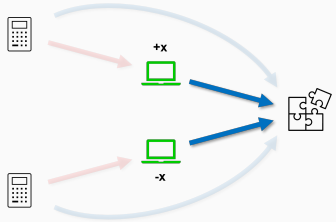


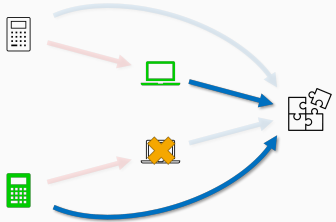
Patent, License and Trade Secret: Optimal License Fee

Proposition

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

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





Patent, License and Trade Secret: Optimal License Fee

Observation

- $V_C = \dfrac{\lambda_H \Pi - c}{2\lambda_H}$: each firm's expected payoff when they race with the new tech.
- $\dfrac{x^*}{V_C} = \dfrac{\lambda_H - \lambda_L}{\lambda_H + \lambda_L} \cdot \dfrac{\lambda_H \Pi + c}{\lambda_H \Pi - c}$ is decreasing in Π
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