Strategic Concealment in Innovation Races

Yonggyun (YG) Kim

Florida State University

Francisco Poggi

University of Mannheim

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Introduction

- Innovations often build on existing knowledge.
- Access to knowledge is crucial in determining the direction of firms' innovation efforts.
- **General question**: How is knowledge acquired and disseminated in innovation races?

Introduction

- Race paths are seldom unique.
  - COVID-19 Vaccine: mRNA or viral vector technologies.
  - Self-driving vehicles: LIDAR or radar technologies.

- Competitors must decide how to allocate resources (e.g. time, money) across the different paths.

- **Q1**: How do firms' decisions hinge on their competitors' choices and progress?

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- Firms might not access opponent's breakthroughs due to (e.g. efficient delivery method)
  - Trade secrets.
  - Proprietary technology.

- This lack of access might introduce inefficiencies:
  - Duplication costs.
  - Suboptimal technology.

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What we do

- We study a model of innovation race in which
  - Multiple technologies can be used to win the race.
  - Using some technologies requires obtaining them first. (**firm-specific**).
  - Firms flexibly choose between
    - racing with already available technology.
    - try to obtain a better technology.
- We analyze the strategic behavior of firms in different information environments.
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- We apply this model to study incentives to disclose, patent, and license technological discoveries.

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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)
- **Hail-Mary Attempts**: Carnehl, Schneider ('22); Kim ('22)

Preview of results

- Without patents, firms do not disclose or share their technology. This entails inefficiencies that slow down innovation.
- When technology access is public information, patents are effective in inducing faster innovation.
  - Patents facilitate licensing, and firms are willing to share technologies with rivals for an adequate license fee.
- When technology access is private information, patents might be ineffective.
  - When stakes are sufficiently high, firms don't apply for patents to conceal their technology access.
  - True even when the patent holder has all the bargaining power in potential licensing negotiations.
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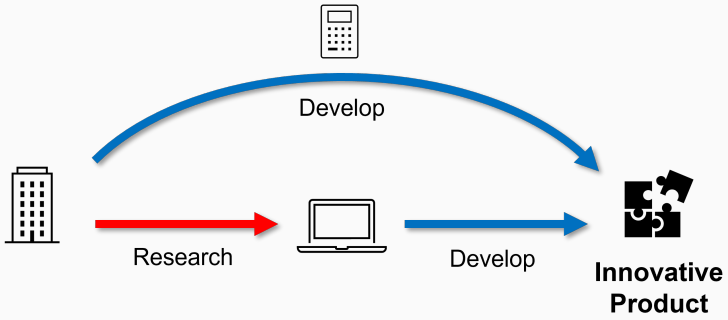
Preview of Framework



1. Model

2. Benchmark: Constant Development Rate

3. Public Information Setting

4. Private Information Setting

5. Patents and Licensing

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) privately allocates a unit of resources to:
  - **Research:** trying to obtain the new technology.
  - **Development:** trying to win the race with the currently available technology.
- **Research progress** of a firm indicates whether they obtained the new technology.

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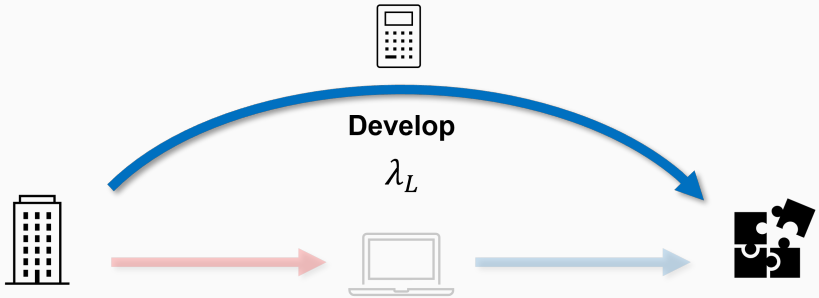

Old Technology

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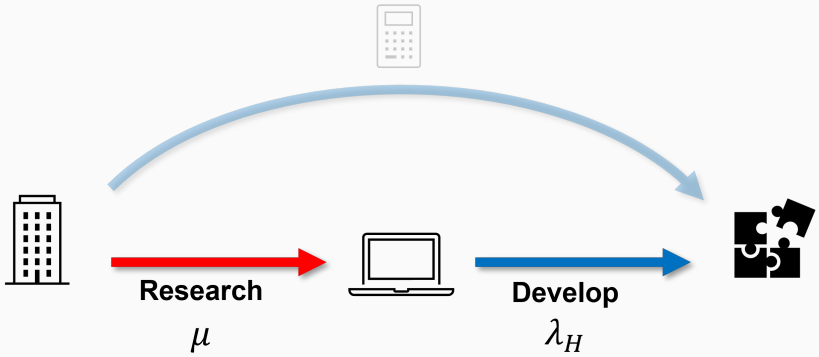

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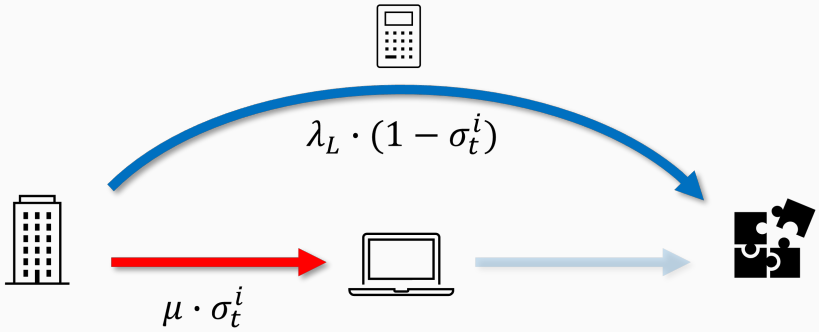

Partial Allocation

Model: Payoffs

- The race ends when either firm develops the innovative product.
  - Winner obtains lump-sum prize Π.
  - Both firms pay a flow cost c throughout the race.

- Thus, the final payoff of Firm i is:

$$\mathbb{1}_{\{i \text{ is the winner}\}} \cdot \Pi - c \cdot T$$

where T is the time at which the race ends.

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Model: Parametric Assumptions

1. **A1:** The new technology path (R + D) is (in expectation) faster than the old technology path:

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

2. **A2:** Developing with the old technology is profitable:

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

   - This assumption ensures that firms never exit the race.

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Model: Information

- Resource allocation is private information.
- Development of the innovative product is publicly observed.

- What about **research progress** of firms?
  - First part of the paper: we analyze **public** and **private**.
  - Second part of the paper: we extend the model to allow for voluntary disclosure through **patents**.

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Benchmark: Constant Development Rate

- Suppose that the rival develops the innovative product at a constant rate λ.
  - Which path is optimal?

Lemma

Suppose the rival's develops at a constant rate λ. There is a threshold $\lambda_\star$ such that

(a) if $\lambda < \lambda_\star$, it optimal to conduct research;

(b) if $\lambda > \lambda_\star$, it is optimal to develop with the old technology.

Moreover,

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

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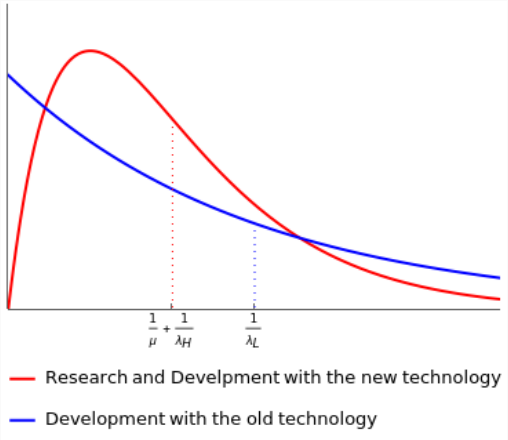
Development Times



PDF of the innovation time without race

Long Run:

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

Short Run:

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

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Public Information Setting

- **Public information setting**: research progress of both firms is public information.

- **Strategy**: resource allocations contingent on entire history.
- **Markov strategy**
  - State variable: research progress of firms.

- **Observation:** A firm with the new technology conducts zero research.
  - It's only relevant to characterize what do firms do when they don't have the new technology.

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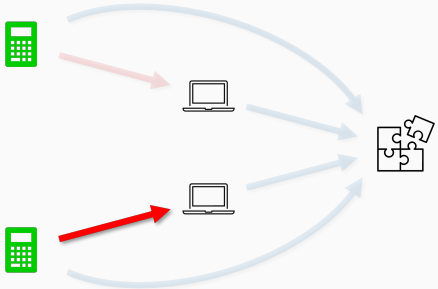
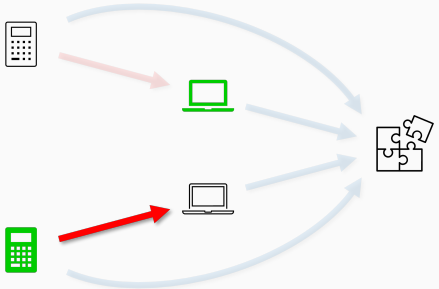
Benchmark Strategy 1: Research Strategy

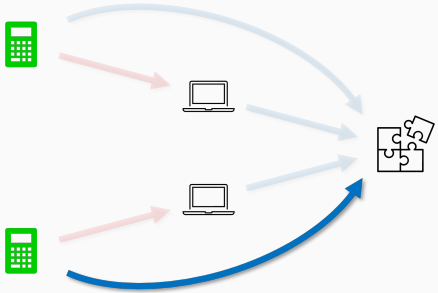
Research Strategy: Do research regardless of the rival's technology.

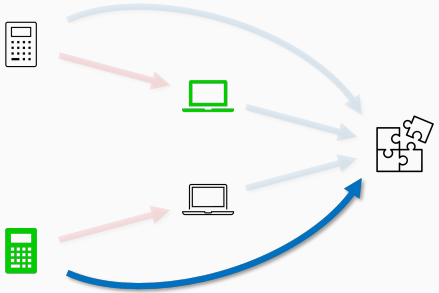




Benchmark Strategy 2: Direct-Development Strategy

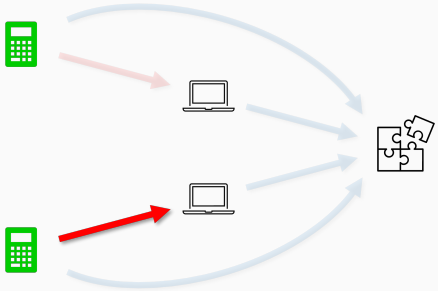
Direct-Development Strategy: Develop with old technology regardless of the rival's progress.

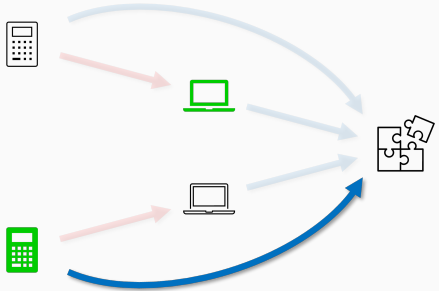




Fall-Back Strategy

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





Public Information: MPE Characterization

Theorem 1

Suppose that 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;
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- **Remark**: symmetry is obtained as a result.
- **Immediate part**:
  - $\lambda_\star < \lambda_H$ implies that firms develop with the old technology when opponent has the new one.
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- **Not-so-immediate part:**
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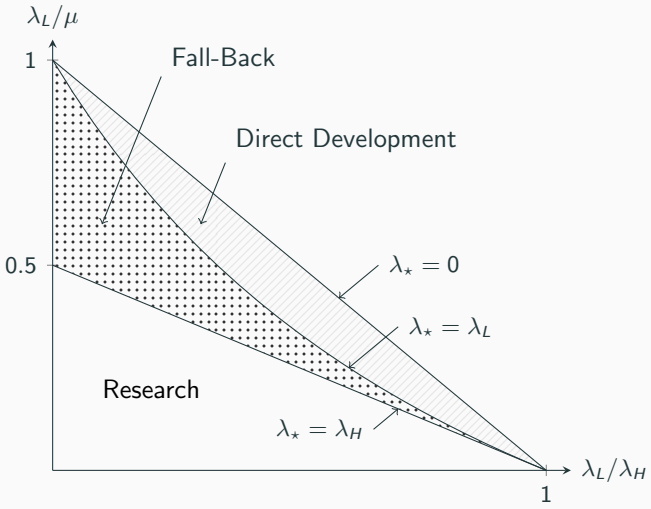

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Private Information: Strategies

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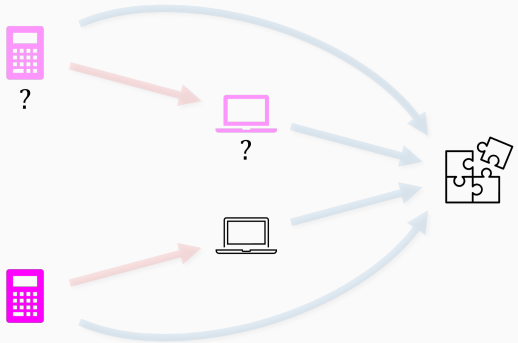

Allocation policy: $\sigma : \mathbb{R}_+ \to [0, 1]$

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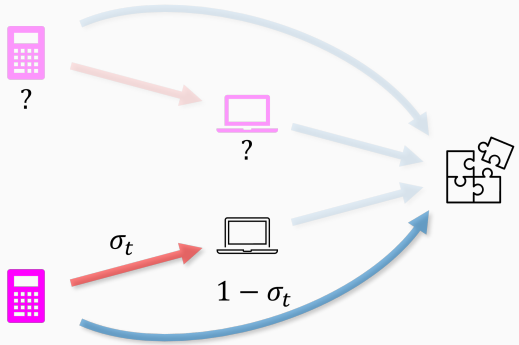

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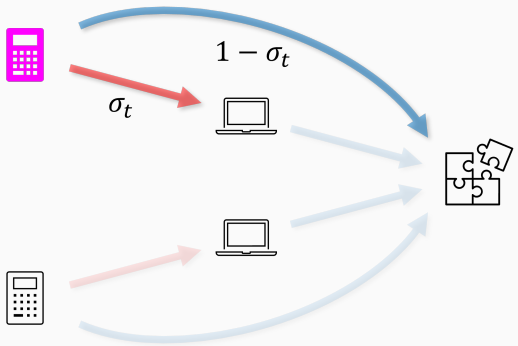
- Given the rival's policy σ, the firm forms a belief p



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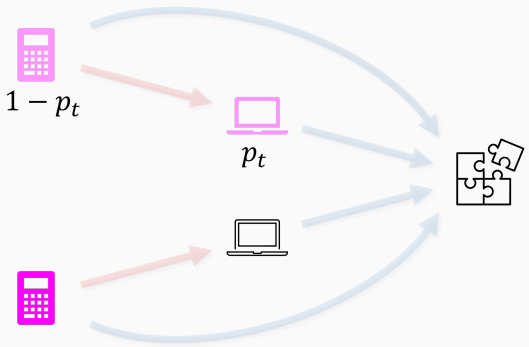

Private Information: Evolution of Beliefs

- p_t : probability that a firm has the new technology at time t given no success in product development.

Lemma: Evolution of Beliefs

Given allocation policy σ, p_t is characterized by the initial condition $p_0 = 0$ and

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

- **Duration Effect (DE)**: As more resources are allocated to research, it is more likely that the firm has the new technology.
- **Still-in-the-Race Effect (SRE)**: Lack of success in product development indicates that it is less likely that the firm has the new technology.

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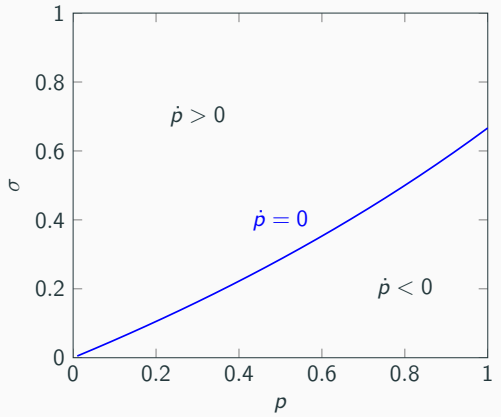

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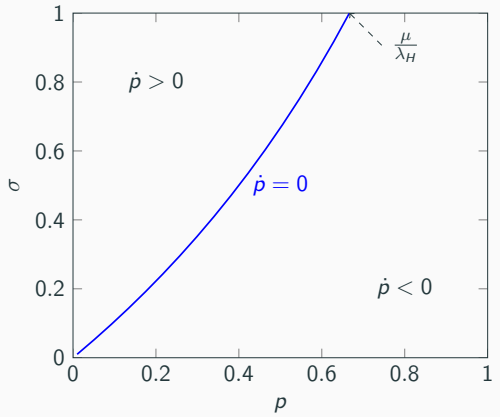

(b) $\mu < \lambda_H$

Private Information: Equilibrium Concept

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

- h_t^σ: the associated development rate

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

Private Information: Equilibrium Concept

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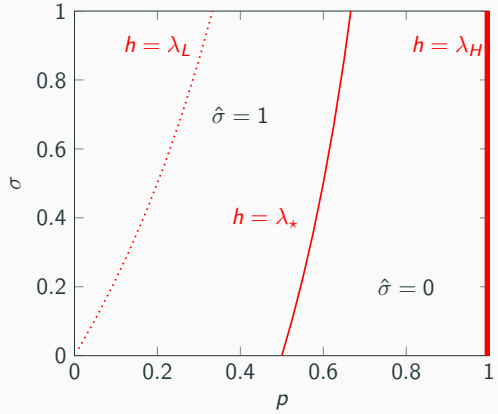
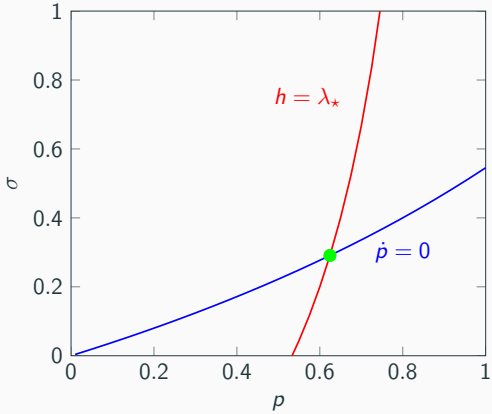
Private Information: Iso-development-rate Curve and Best Responses



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

$\hat{\sigma}$ is the best response for h constant.

Private Information: Steady State

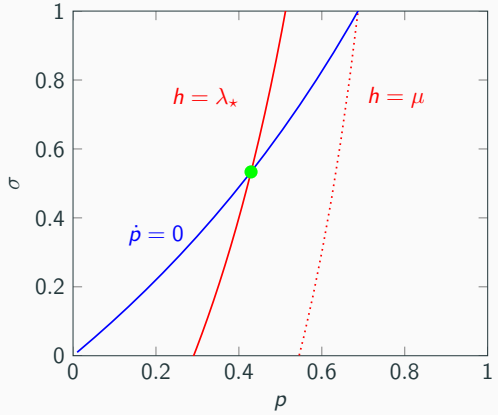


$\mu > \lambda_H$ and $\lambda_H > \lambda_\star > \lambda_L$

A pair $(p_\star, \sigma_\star)$ a *steady state* if $\dot{p} = 0$ and $h = \lambda_\star$

Lemma: the steady state exists iff $\lambda_\star \in (\lambda_L, \min\{\mu, \lambda_H\})$. Moreover, it is unique when it exists.

Private Information: Steady State



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

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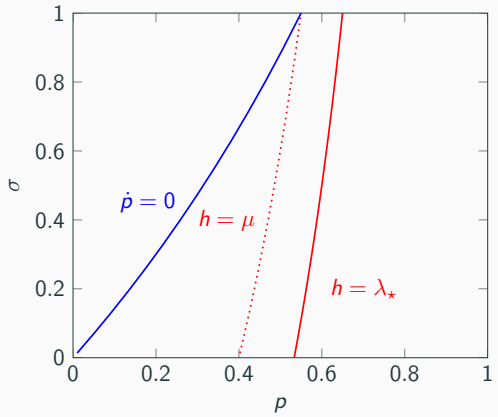

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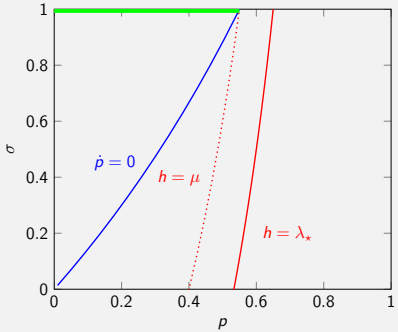
Private Information: Nash Equilibrium with Monotone Development Rate

Theorem 2

When firms' research progress is private information, these are 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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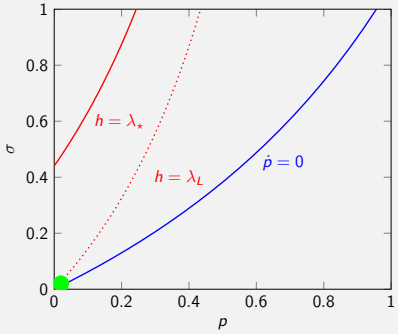

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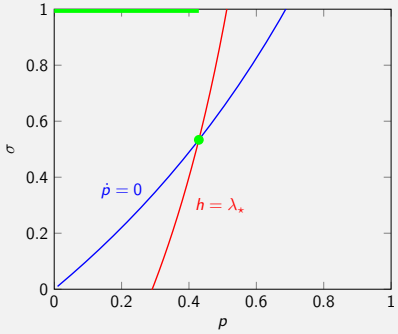

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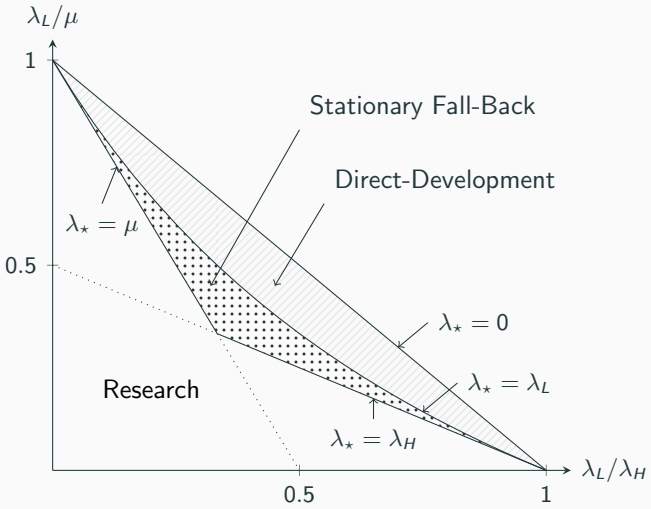
Private Information: Uniqueness

- The equilibrium described in the previous theorem is the unique equilibrium:
  - with monotone development rates.
  - symmetric with monotone probabilities p.

Private Information: Nash Equilibrium with Monotone Development Rate



1. Model

2. Benchmark: Constant Development Rate

3. Public Information Setting

4. Private Information Setting

5. Patents and Licensing

Patents

- We extend the model by allowing firms to patent & licensing of 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.
- Patent applications are public information and granted:
  - With probability 1 if rival doesn't have the technology.
  - with probability $\alpha \in [0, 1]$ if rival has new the technology.
- Patent gives the exclusive right to use the new technology and the right to license (TIOLI).

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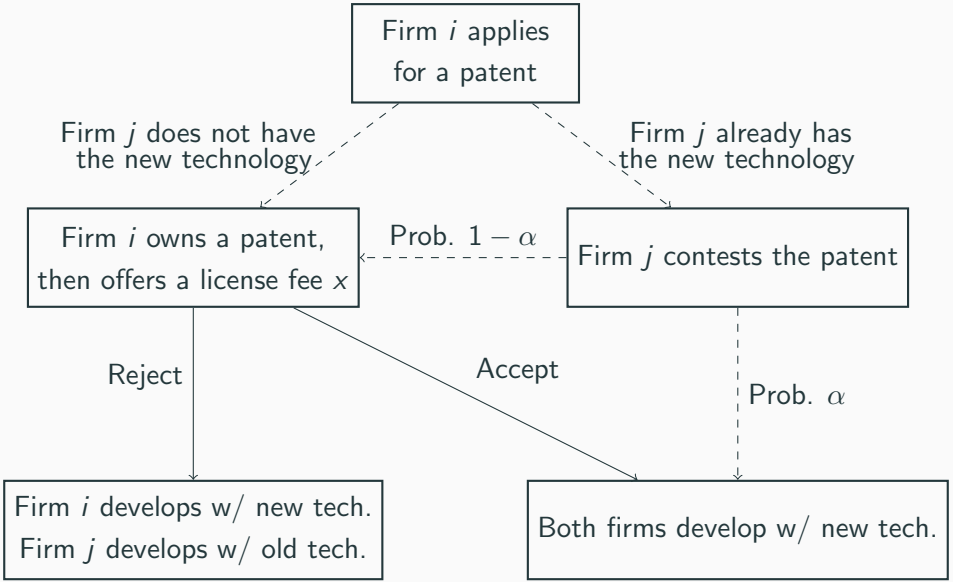
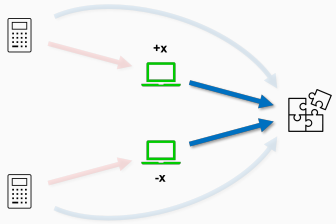

Firm i applies for a patent
Firm j does not have the new technology
Firm j already has the new technology
Firm i owns a patent, then offers a license fee x
Prob. $1-\alpha$
Firm j contests the patent
Reject
Accept
Prob. α
Firm i develops w/ new tech.
Firm j develops w/ old tech.
Both firms develop w/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

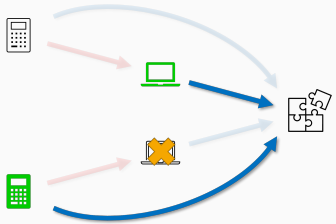
Patents and Licensing: Optimal License Fee

Proposition

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

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





Patent and Licensing: 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

- **Intuition**: the license fee is related to the savings in the race costs.

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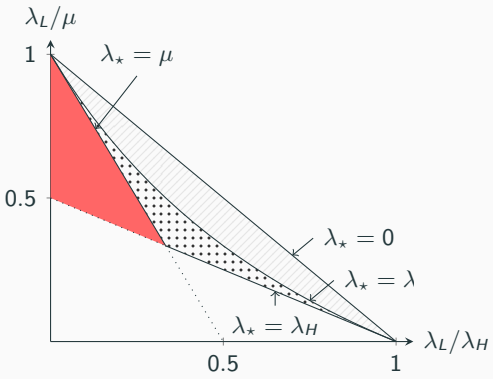
Patents and Licensing: Equilibrium



- Focus on $\lambda_H > \lambda_\star > \mu$
- Public info: fall-back strategy
- Private info: research strategy

Equilibria

- **Efficient Patent Equilibrium**: firms conduct research and apply for patents once they discover the new tech.

- **Concealment Equilibrium**: firms conduct research and do not apply for patents at all.

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Proposition

The **efficient patent equilibrium** exists if

$$\frac{x^*}{V_C} > \frac{\lambda_H}{\lambda_H + \mu(2-\alpha)} \tag{1}$$

Necessary and sufficient conditions

(i) if $\alpha \leq \frac{2\lambda_\star}{\lambda_H+\lambda_\star}$, (1) holds

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Patent and Licensing: Concealment Equilibrium

Proposition

The **concealment equilibrium** exists if

$$\frac{x^*}{V_C} < \frac{\lambda_H(\lambda_H - \mu)}{(\lambda_H + \mu)(\lambda_H - \alpha\mu)} < \frac{\lambda_H}{\lambda_H + \mu(2-\alpha)}. \tag{2}$$

Necessary and Sufficient Conditions

There exists $\tilde{\Pi}(\alpha) > \hat{\Pi}(\alpha)$ such that (2) holds iff $\alpha > \frac{2\lambda_\star}{\lambda_H + \lambda_\star}$ and $\Pi > \tilde{\Pi}(\alpha)$.

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Patents and Licensing: 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 right from 'first-to-invent' to 'first-to-file')
  - Caveat: too low Π may induce the firms to exit the race.

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

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Thank you!