Researcher's Dilemma

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Motivation

Scientists aim at establishing priority of discovery (Merton 1957).

Priority is a form of property right : recognition, prizes, patents (Stephan 1996).

The race for priority speeds up the maturation process, which may decrease research quality.

Technological progress may also speed up the maturation process while increasing research quality.

The overall impact on research quality is a priori ambiguous.

A Case in Point : Darwin vs Wallace

After his attention was drawn in 1856 to a paper by Alfred Russel Wallace on the "introduction of new species," Darwin was torn between the desire to produce a complete account of his theory and its applications, and the urgency of publishing a short paper summarizing its main insights.

This process took place "in the dark," without the competitors knowing about their opponent. It is only when Darwin realized that he had been "forestalled" and was running the risk of losing priority that he decided to "publish a sketch of [his] general views in about a dozen pages or so" (Darwin 1887).

What We Do in this Paper

We build a parsimonious strategic model in which the quality of research outputs is determined by the interplay between the dynamics of researchers' innovative abilities, the growth potential of research projects, and the technology that researchers have at their disposal.

This model gives insights into several questions :

(i) How does competition affect the way researchers let their ideas mature ?
(ii) Do technological progress or human-capital accumulation necessarily foster research quality ?
(iii) How do different types of asymmetries between researchers affect their equilibrium behavior ?

Other Applications

Our setting is relevant for a broad range of empirical issues :

$\Rightarrow$ Should a software company launch a new application at the earliest opportunity, or should it develop it to make sure that the software is free of bugs, user-friendly, and compatible with other applications ?

$\Rightarrow$ How many tests a pharmaceutical company should conduct before patenting a molecule it has discovered and that may cure a disease, in order to assess its effectiveness and possible side effects ?

Players, Actions, Payoffs

There are two players $i = a, b$, each of whom has a breakthrough at some random time τ^i.

Each player i can move at any time $t^i \geq \tau^i$; $m^i \equiv t^i - \tau^i$ is player i's maturation delay.

If player i moves first at time t^i, she obtains a payoff $L(t^i - \tau^i, \tau^i)$ evaluated in time-τ^i terms, while player j obtains a zero payoff.

If players a and b simultaneously move at time t, they obtain payoffs $\alpha L(t - \tau^a, \tau^a)$ and $\alpha L(t - \tau^b, \tau^b)$, for some $\alpha \in [0, 1]$.

Returns to Maturation

Assumption 1 *The function L is continuous over $[0,\infty)\times[0,\infty)$ and thrice continuously differentiable over $(0,\infty)\times(0,\infty)$. For each τ, there exists $M(\tau)>0$ such that*

$$
\begin{aligned}
L(0,\tau) &= 0, & \\
L(m,\tau) &> 0, & m > 0, \\
L_1(m,\tau) &> 0, & M(\tau) > m > 0, \\
L_1(m,\tau) &< 0, & m > M(\tau), \\
L_{11}(M(\tau),\tau) &< 0. &
\end{aligned}
$$

Assumption 2 *For each τ,*

$$
(\ln L)_{11}(m,\tau) < (\ln L)_{12}(m,\tau), \quad M(\tau) \geq m > 0.
$$

The Publication Example

m is the delay between a breakthrough and the first submission of the corresponding paper to a journal.

$D(m, \tau)$ is the publication delay, reflecting the number and length of refereeing rounds.

There are positive and decreasing returns to maturation, $D_1 < 0$ and $D_{11} > 0$. Very immature papers get stuck in the refereeing process, $D(0, \tau) = \infty$.

Researchers compete for a unit publication prize and discount future payoffs at rate r,

$$\begin{aligned} L(m, \tau) &= \exp(-r(m + D(m, \tau))), \\ M(\tau) &= \arg\min \{m + D(m, \tau))\}. \end{aligned}$$

Information

τ^a and τ^b are independently and identically distributed according to a continuously differentiable distribution G with $\dot{G} > 0$ over $[0, \infty)$; τ^i is player i's private information.

The only public information that accrues to each player during the course of the game is whether and when her opponent moves, which effectively terminates the game.

Strategies, Payoffs, Equilibria

A pure strategy for player i is a mapping $\sigma^i : [0,\infty) \to [0,\infty)$ such that $\sigma^i(\tau^i) \geq \tau^i$ for all $\tau^i \geq 0$.

Player i's payoff if her type is τ^i, player j's strategy is σ^j, and player i intends to make a move at time $t^i \geq \tau^i$ is

$$V^i(t^i, \sigma^j, \tau^i) \equiv \{\mathbf{P}[\sigma^j(\tau^j) > t^i] + \alpha \mathbf{P}[\sigma^j(\tau^j) = t^i]\} L(t^i - \tau^i, \tau^i).$$

(σ^a, σ^b) is an equilibrium if for all $i = a, b$, $\tau^i \geq 0$, and $t^i \geq \tau^i$,

$$V^i(\sigma^i(\tau^i), \sigma^j, \tau^i) \geq V^i(t^i, \sigma^j, \tau^i).$$

Preliminary Results

Lemma 1 *In any equilibrium,*

(i) $0 < \sigma^i(\tau^i) - \tau^i \leq M(\tau^i)$ *for all* τ^i.
(ii) σ^i *is strictly increasing*.
(iii) $\sigma^a(0) = \sigma^b(0) \equiv \sigma(0)$.
(iv) σ^i *is continuous, so that* $\sigma^i([0, \infty)) = [\sigma(0), \infty)$.
(v) $\phi^i \equiv (\sigma^i)^{-1}$ *is differentiable over* $[\sigma(0), \infty)$.

First-Order Conditions

Type τ^i of player i maximizes

$$\mathbf{P}[\sigma^j(\tau^j) > t^i]L(t^i - \tau^i, \tau^i) = [1 - G(\phi^j(t^i))]L(t^i - \tau^i, \tau^i).$$

The first-order condition is

$$[1 - G(\phi^j(t^i))]L_1(t^i - \tau^i, \tau^i) = \dot{G}(\phi^j(t^i))\dot{\phi}^j(t^i)L(t^i - \tau^i, \tau^i).$$

In equilibrium, $\tau^i = \phi^i(t^i)$, and we get a differential system

$$\dot{\phi}^j(t) = \frac{1 - G}{\dot{G}}(\phi^j(t))\,\frac{L_1}{L}(t - \phi^i(t), \phi^i(t)), \quad t \geq \sigma(0).$$

The Fundamental ODE

Lemma 2 *Any equilibrium is symmetric and characterized by*

$$\begin{aligned} \dot{\phi}(t) &= f(t, \phi(t)), \quad t \geq \sigma(0), \\ f(t,\tau) &\equiv \frac{1-G}{\dot{G}}(\tau)\,\frac{L_1}{L}(t-\tau,\tau), \quad (t,\tau) \in \mathcal{D}, \\ \mathcal{D} &\equiv \{(t,\tau) : 0 \leq \tau \leq t \leq \tau + M(\tau)\}. \end{aligned}$$

$\sigma(0)$ must be chosen so that ϕ never leaves $\mathcal{D}$.

The vector field is outward pointing on the boundary of $\mathcal{D}$.

A maturation delay equal to M is not consistent with equilibrium.

Existence of Equilibrium

Theorem 1 An equilibrium exists.

This follows from a connectedness argument (Ważewski 1947).

Uniqueness of Equilibrium

A priori, multiple initial conditions $\sigma(0)$ may be consistent with equilibrium.

Assumption 3 $\liminf_{\tau\to\infty}\{M(\tau)\} < \infty$.

Assumption 4 *There exists* $\rho > 0$ *such that*, *for each* τ, $L(\cdot,\tau)$ *is* ρ*-concave over* $[0, M(\tau)]$.

Theorem 2 *The equilibrium is unique.*

If there were two equilibria, then

$$\sigma_1(\tau) - \sigma_2(\tau) \geq [\sigma_1(0) - \sigma_2(0)] \exp\left(\rho \int_0^\tau \frac{\dot{G}}{1-G}(\theta)\,\mathrm{d}\theta\right).$$

Comparative Statics

Comparative-statics results follow along the same logic as the uniqueness result.

Corollary 1 $\overline{\sigma} > \underline{\sigma}$ if $\underline{\dot{G}}/(1-\underline{G}) > \dot{\overline{G}}/(1-\overline{G})$ or $\overline{L}_1/\overline{L} > \underline{L}_1/\underline{L}$.

If researchers are less innovative or have less fear of ruin (Aumann and Kurz 1977), they let their projects mature more.

In the publication example, this is the case if $\underline{r} < \overline{r}$: young researchers on a tenure track are relatively more eager to get their papers published fast, and are thus more willing to let their breakthroughs mature.

Maturation Delays

Human-capital accumulation or technological progress modify the research environment in two ways :

(i) They make researchers more innovative : the breakthrough rate $\dot{G}/(1-G)$ may increase over time.

(ii) They make researchers more efficient : the growth potential $(L_1/L)(\cdot,\tau)$ of a time-τ breakthrough may increase with τ.

Corollary 2 *If the mapping*

$$\tau \mapsto \frac{\dot{G}}{1-G}(\tau)\,\frac{L}{L_1}(m,\tau) - 1$$

has a positive (negative) derivative over $\mathcal{T}_m \equiv \{\tau : m < M(\tau)\}$ *for all* $m > 0$*, then* $\mu(\tau)$ *is strictly decreasing (increasing) in* τ*.*

Maturation Delays in the Publication Example

If $D_{12} > 0$, then $(L_1/L)_2 < 0$: the publication process becomes a better substitute to the time researchers spend developing their breakthroughs. Then equilibrium maturation delays decrease if researchers become increasingly innovative.

If the breakthrough rate increases enough, researchers have an incentive to write only "quick-and-dirty" papers, and the total time from breakthrough to publication tends to increase.

Researchers engage into defensive publication *because* both the research community and the publication process become more efficient over time.

Research Quality

The relationship between maturation delay and research quality is not univocal : improved technology can make researcher more efficient at developing breakthroughs.

The quality of a research output depends on the maturation delay and on the breakthrough time. For instance,

$$Q(m,\tau) = d\xi(\tau)m + (1-d)\int_{\tau}^{\tau+m} \xi(s)\,\mathrm{d}s,$$

where d is the distance to the technological frontier.

An decrease in d may lead to shorter equilibrium maturation delays, but unambiguously raises research quality levels.

Asymmetric Players : The Hare and the Tortoise

Consider two players a (the hare) and b (the tortoise) with constant but different breakthrough rates $\lambda^a > \lambda^b$. For simplicity, payoffs no longer directly depend on the breakthrough time.

Letting $\nu^i(\tau) \equiv t - \phi^i(t)$, a continuous equilibrium is associated to an autonomous system

$$\dot{\nu}^i(t) = 1 - \frac{1}{\lambda^i}\frac{\dot{L}}{L}(\nu^j(t)).$$

Theorem 3 There exists a unique continuous equilibrium.

Economic Implications

Given any breakthrough time, the gap between the hare's and the tortoise's maturation delays increases over time. Thus the hare always choose longer maturation delays than the tortoise, no matter when they have their breakthroughs.

$\Rightarrow$ More innovative researchers always produce more elaborate works than their less innovative opponents.

$\Rightarrow$ Within a group of competing researchers, speed of discovery and maturation of ideas should be positively correlated.

This reverses the correlation that would be computed across noncompeting groups of researchers with different aptitudes.

Concluding Comments

Our analysis points at new kinds of Schumpeterian effects :

(i) Technological progress, by making innovators apter at finding new ideas, has a detrimental effect on innovation quality by increasing the competition for priority.

(ii) By contrast, factors that affect how researchers can develop their breakthroughs have a positive impact on research quality, both over time and in a cross-section.