On the optimal timing of innovation and imitation

E. Billette de Villemeur, R. Ruble, B. Versaevel[1]

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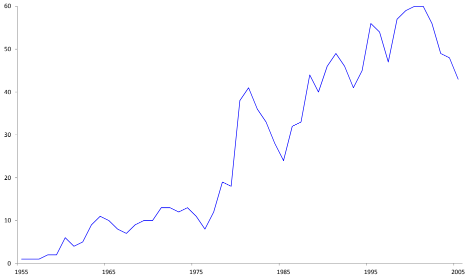
[1] Billette de Villemeur: Université de Lille & LEM CNRS, France; Ruble and Versaevel: EMLYON Business School (primary affiliation) & GATE CNRS, France; corresponding author: ruble@em-lyon.com

Research questions

"Compared with the situation 50 years ago, the worldwide incidence of dengue has risen 30-fold." (WHO, 2012)



number of countries reporting dengue cases

source: http://apps.who.int/globalatlas/DataQuery/default.asp

Research questions

Contrasting imitation conditions in *drug vs. vaccine* businesses:

Drugs: low cost of imitation by generic entrants

Vaccines: "there is technically no such thing as a generic vaccine"

→ *How do conditions of imitation impact:*

1) *dynamics of innovation and imitation?*
2) *economic welfare (industry and consumers)?*
3) *incentives for innovator to change market access conditions?*
(e.g., higher cost of reverse engineering; license agreement)

The Model

Structural assumptions

- Two ex-ante symmetric firms
- Growing market with uncertain future demand
- Flow profit π_M or π_D scaled by a state variable Y_t with GBM: $dY_t = \alpha Y_t dt + \sigma Y_t dZ_t$, Y_0 small, interest rate $r > \alpha$
- Endogenous fixed cost of discrete investment

  I for innovator (= 1st investor)

  K for imitator (= 2nd investor)

A standard "real option game" except $K \neq I$

Timing

Firms i, j, $j \neq i$, non-cooperatively choose investment thresholds.

Two-stage game:

- stage 1: firms choose *initial* investment thresholds (Y_i, Y_j) that determine *innovator* and *imitator* roles;
- stage 2: if a firm (i) *innovates* by investing first at $Y_i \leq Y_j$, the other firm (j) then *imitates* by investing at Y_F^*.

Solving the game backwards, we look for a NE in (Y_i, Y_j).

Payoffs

Innovator (leader) payoff:

$$\mathbb{E}_{Y_t}\left\{\int_{\tau_i}^{\tau_F^*} \mathrm{e}^{-r(s-t)} Y_s \pi_M \mathrm{d}s - \mathrm{e}^{-r(\tau_i - t)} I + \int_{\tau_F^*}^{\infty} \mathrm{e}^{-r(s-t)} Y_s \pi_D \mathrm{d}s\right\}$$

Imitator (follower) payoff:

$$\mathbb{E}_{Y_t}\left\{\int_{\tau_F^*}^{\infty} \mathrm{e}^{-r(s-t)} Y_s \pi_D \mathrm{d}s - \mathrm{e}^{-r(\tau_F^* - t)} K\right\}$$

with stopping times:

$\tau_i \equiv \min\{t \geq 0 : Y_t \geq Y_i\}$

$\tau_F^* \equiv \min\{t \geq 0 : Y_t \geq Y_F^*\}$

Payoffs (Dixit and Pindyck, 1994)

Innovator (leader) payoff:

$$L_{Y_t}\left(Y_i, Y_F^*\right) = \underbrace{\left(\frac{\pi_M}{r-\alpha}Y_i - I\right)\left(\frac{Y_t}{Y_i}\right)^{\beta}}_{\text{present value of monopoly profit flow}} + \underbrace{\frac{\pi_D - \pi_M}{r-\alpha}Y_F^*\left(\frac{Y_t}{Y_F^*}\right)^{\beta}}_{\text{effect of rival's entry}}$$

Imitator (follower) payoff:

$$F_{Y_t}\left(Y_i; K\right) = \underbrace{\left(\frac{\pi_D}{r-\alpha}Y_i - K\right)\left(\frac{Y_t}{Y_i}\right)^{\beta}}_{\text{present value of duopoly profit flow}}$$

where $Y_F(K)$ is the imitator value maximizing threshold with $\beta\left(\alpha, \sigma, r\right) > 1$ decreasing in α, σ

Innovation & Imitation Dynamics

Nature of strategic competition driven by imitation cost K:

Proposition 1

The duopoly investment game has a unique symmetric equilibrium and there exists an imitation cost threshold $\widehat{K} \leq I$ such that:

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Proposition 1

The duopoly investment game has a unique symmetric equilibrium and there exists an imitation cost threshold $\widehat{K} \leq I$ such that:
(i) if $K < \widehat{K}$ firms play a game of *attrition*. The randomized innovator investment threshold $\widetilde{Y}_i$ is bounded below by Y_L; and the imitator investment occurs at Y_F^*.
(ii) if $K = \widehat{K}$ firms invest at standalone thresholds $(Y_L, Y_F(\widehat{K}))$.
(iii) if $K > \widehat{K}$ firms play a game of *preemption*. The innovator and imitator investment thresholds are $Y_P < Y_L$ and $Y_F(K)$.

$$Y_P \leq Y_L \leq Y_F(K) \leq Y_F^* := \sup\left\{Y_F(K), \widetilde{Y}_i\right\}$$

Social Welfare Optimum

We study welfare as a function of $K \equiv$ a policy instrument (e.g., strength of IP protection).

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The **industry perspective**?

There is rent dissipation under both attrition and preemption:

$$E\left(V_i\right) = \min\left\{L\left(Y_L^*, Y_F^*\right), F\left(Y_F(K); K\right)\right\}.$$

K increases $\Rightarrow L\left(Y_L^*, Y_F^*\right)$ increases, $F\left(Y_F(K); K\right)$ decreases, so:

Proposition 2

Viewed as a function of imitation cost K, expected industry value is initially constant ($K < \widetilde{K}$), single-peaked, and attains its maximum when neither attrition nor preemption occur ($K = \widehat{K}$).

What about **consumers**? For a consumer surplus CS_M or CS_D scaled by Y_t the expected welfare $\mathbb{E}_{\widetilde{Y}_i,\widetilde{Y}_j} W(K)$ is

$$\mathbb{E}_{\widetilde{Y}_i,\widetilde{Y}_j}\Bigg[\underbrace{2V\left(\widetilde{Y}_i,\widetilde{Y}_j\right)}_{\text{industry value}} + \underbrace{\frac{\mathrm{CS}_M}{r-\alpha}\left(\min\left\{\widetilde{Y}_i,\widetilde{Y}_j\right\}\right)^{-(\beta-1)} Y_t^{\beta}}_{\text{consumer surplus from innovation}}$$

$$+\underbrace{\frac{(\mathrm{CS}_D-\mathrm{CS}_M)}{r-\alpha} Y_F^{*-(\beta-1)} Y_t^{\beta}}_{\text{consumer surplus from imitation}}\Bigg]$$

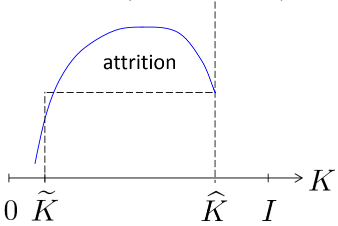
Industry value (first term) is maximized at $\widehat{K}$.

A higher K *accelerates* innovation, but *decelerates* imitation.

A *local* social optimum $K_A \leq \widehat{K}$ in attrition ?

$K \leq \widehat{K}$: investment thresholds are $\min\left\{\widetilde{Y}_i, \widetilde{Y}_j\right\}, Y_F^*$

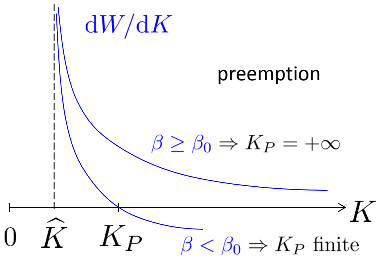
$$lim_{K\uparrow\widehat{K}}\mathrm{d}\left(\mathrm{E}_{\widetilde{Y}_i,\widetilde{Y}_j}W(K)\right)/\mathrm{d}K < 0$$



$\Rightarrow \exists\ K_A$ in $(\widetilde{K}, \widehat{K})$.

A *local* social optimum $K_P \geq \widehat{K}$ in preemption ?

$K \geq \widehat{K}$: investment thresholds are Y_P, $Y_F(K)$



$\Rightarrow$ $\exists$ K_P finite if $\beta < \beta_0$ (high volatility) and $K_P = +\infty$ otherwise.

The *global* social optimum K^*?

(1) A social optimum can involve attrition ($\widetilde{K} < K^* = K_A \leq \widehat{K}$)

(Suppose $CS_M = 0 < CS_D$: innovator perfectly price discriminates)

(2) A social optimum can involve preemption ($\widehat{K} < K^* = K_P$)

(Suppose $CS_D - CS_M = 0$: product market collusion)

(3) More generally:

Corollary 4

Suppose the static private entry incentive is "socially excessive" ($\pi_D \geq (CS_D + 2\pi_D) - (CS_M + \pi_M)$). Then, *preemption* is socially optimal if $CS_M / \pi_M \geq \Omega(\beta)$.

With a sufficiently high β the condition is satisfied for a given demand specification (e.g., $\beta \geq 3.14$ and $P = a - bQ$).

Extensions

Extension 2: licensing agreement (here with $2\pi_D \leq \pi_M$)

Redefine:

$K := K_0 + K_I$; where K_I relates to transferable part of technology, which is avoidable if license fee φ paid to the innovator

- Stage 1": both firms select initial entry thresholds (Y_i, Y_j)
- Stage 2": if a single firm (i) innovates, it proposes a license contract involving lump sum transfer φ substituted for K_I
- Stage 3": the remaining firm (j) decides whether or not to accept the contract and selects its entry threshold

Extension 2: licensing agreement (here with $2\pi_D \leq \pi_M$)

Innovator allows entry at usual Y_F^* at maximum fee:

$$\varphi^* = K_I$$

$$\Rightarrow L_{lic}(Y_i, \varphi^*) > L(Y_i, Y_F^*), \quad F(Y_i; K_0 + \varphi^*) = F(Y_i; K_0 + K_I)$$

In attrition: earlier innovation (stochastically), weakly earlier imitation ($Y_F(K)$ unchanged), higher equilibrium payoffs

In preemption: earlier innovation (deterministically, Y_P lower), same imitation threshold ($Y_F(K)$), unchanged equilibrium payoffs

$\rightarrow$ Licensing increases social welfare

Conclusion

- imitation cost (K) implies either attrition or pre-emption
- no "one size fits all" welfare recommendation $(K^* = K_A, K_P)$
- there must be a *non*-zero cost to imitation $(0 < K_A \leq K_P)$
- usual demand specifications point to optimal pre-emption
- a contract (licensing) is also welfare improving

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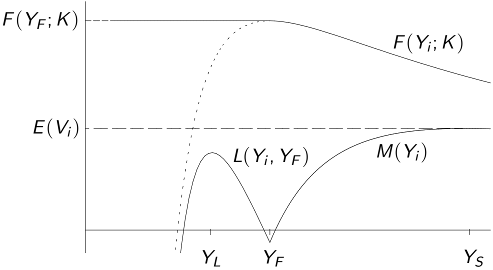
Attrition: $K < \widetilde{K} (< \widehat{K} \leq I)$



$L(Y_L, Y_F) = M(Y_S)$ at $K = \widetilde{K}$; firms mix over $[Y_S, \infty)$, imitator entry is immediate; rent equalization at $E(V_i) = M(Y_S)$.

Attrition: $K < \widetilde{K} (< \widehat{K} \leq I)$

Each firm i's cumulative distribution of first entry thresholds Y_i is

$$G_a\left(Y_i; K\right) = 1 - \exp \int_{Y_S}^{Y_i} \frac{M'(s)}{F\left(s; K\right) - M(s)} ds.$$

Substituting for the functions F and M and integrating gives

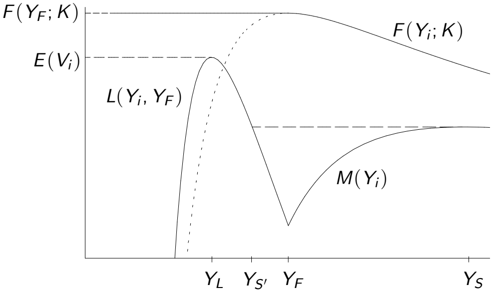
$$G_a\left(Y_i; K\right) = 1 - \left(\frac{Y_i}{Y_S}\right)^{\frac{\beta I}{I-K}} \exp\left\{-\frac{\beta I}{I-K}\left(\frac{Y_i}{Y_S} - 1\right)\right\},$$

and the hazard rate is

$$h_a\left(Y_i; K\right) = \frac{\beta I}{I-K}\left(\frac{1}{Y_S} - \frac{1}{Y_i}\right),$$

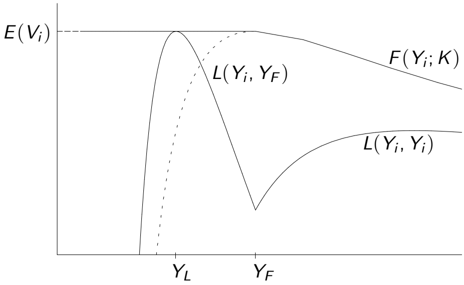
so $\partial h / \partial K \geq 0$: first entry threshold decreases stochastically in K.

Attrition: $\widetilde{K} \leq K < \widehat{K} (\leq I)$



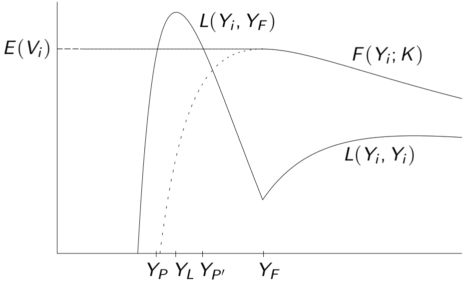
$L(Y_{S'}, Y_F) = M(Y_S)$; firms mix over $[Y_L, Y_{S'}] \cup [Y_S, \infty)$, imitator entry at Y_F or $\widetilde{Y}_i > Y_F$, rent equalization at $E(V_i) = L(Y_L, Y_F)$

Critical case: $K = \widehat{K}$



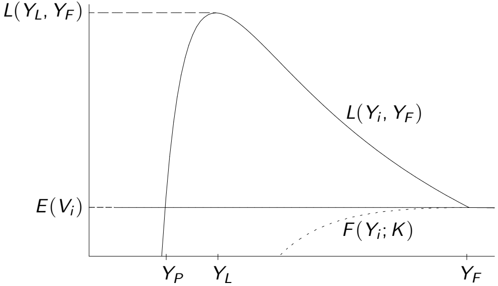
$L\left(Y_L, Y_F\right) = F\left(Y_F; \widehat{K}\right)$, with $\widehat{K} < I$; rent equalization at $E(V_i)$

Preemption: $\widehat{K} \leq K < I$



$L\left(Y_P, Y_F\right) = F\left(Y_F; K\right)$; rent equalization at $E\left(V_i\right) = F\left(Y_F, K\right)$

Preemption: $I \leq K$ (here with equality)



$L(Y_P, Y_F) = F(Y_F; K)$; rent equalization at $E(V_i) = F(Y_F, K)$

Imitation cost thresholds

$\widetilde{K}$: $$L(Y_L, Y_F(\widetilde{K})) = M(Y_S)$$

i.e., the imitation cost that equalizes the maxima of payoff functions L and M

$\widehat{K}$: $$L(Y_L, Y_F(\widehat{K})) = F(Y_F(\widehat{K}); \widehat{K})$$

i.e., the imitation cost that equalizes the maxima of payoff functions L and F