# FIGHTING IMITATION WITH FAST-PACED INNOVATION

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# Fighting Imitation with Fast-Paced Innovation

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**Abstract**

This paper examines how potential imitator entry alters the optimal pace at which an innovative firm introduces successive generations of an evolving product. When the imitator is committed to be in the market, imitation leads the innovative firm to speed up the introduction of new generations, provided that the imitation delay is sufficiently long. If instead the imitator's entry decision is simultaneous with the innovative firm's R&D-intensity decision, we show that the innovating firm never overinvests in R&D; for some values of the imitation delay, it will actually choose to reduce its R&D intensity. Finally, if the imitator's entry decision is made after observing the innovating firm's R&D intensity, for intermediate values of the imitation delay, the innovating firm will overinvest in R&D in order to deter the imitator's entry.

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# 1 Introduction

It has long been recognized that innovation —be it of the product or process type— can be used strategically by an incumbent firm to affect the entry and exit decisions of competitors. For instance, Ordover and Willig (1981) note (p. 22) that "product innovation may be more effective than price-cutting in inducing the exit of a rival because the associated costs to the firm are largely fixed and irreversible. [...] In contrast, a rival's dogged refusal to exit can always motivate a firm to rescind a price cut". Such a strategic use of innovation can take various forms; for instance, the incumbent firm can introduce a new product and price it in such a way as to induce exit by its rival. Alternatively, it can file 'preemptive' patents on new technologies to deny other firms access to them; although such behaviour has not given rise to extensive litigation, prominent cases include *SCM vs Kodack*, *US vs IBM*, and *US vs AT&T*.

The analysis of strategic innovation revolves around issues which have close counterparts in the theory of strategic excess-capacity investment; *e.g.*, how much commitment value is carried by R&D decisions, or how effectively can innovation deter entry (or induce exit). However, whereas the theory of capacity investment as entry deterrence has lead to a body of fairly conclusive results (see Tirole, 1989, for a survey), an innovation-based counterpart of that theory has proved more elusive. A pioneering paper by Gilbert and Newbery (1982) argued that preemptive innovation is a plausible scenario under a wide range of circumstances. They reason as follows. Suppose that an innovative substitute for an existing product can be introduced by the current incumbent or by an entrant. If the incumbent introduces the new product, he can sell it together with his existing product at a price set to maximize profits. By contrast, if the entrant introduces the new product, all he can hope for is to sell it in competition with the incumbent's existing product, at a price set noncooperatively. Because the new product is worth more to the incumbent than to the entrant, the incumbent rationally chooses to spend more on R&D in order to preempt entry. Generalizing this example suggests that incumbent firms will innovate more than entrants and are unlikely to be unseated by entrants with new products. Gilbert and Newbery's paper set off an intense controversy (see Reinganum, 1983; Salant, 1984, and Lippman and Mamer, 1992). In particular, Reinganum stressed the tension between a monopolist's ability to appropriate the returns from innovation and his concern over the cannibalization of his existing products, suggesting that incumbents may in fact have *lesser* incentives than entrants to introduce new products. Although important results were generated as a by-product of the controversy, it is fair to say that the state of the debate is, to this day, rather unconclusive.[1]

This paper considers a particular but important case in which the entrant can imitate the incumbent's existing product but cannot develop new substitutes. Thus, we

[1] See the survey by Reinganum (1989) for a summary of the literature's results. On the related issue of predatory product introduction, see Ordover and Saloner (1989).

focus not upon the R&D rivalry between the incumbent and the imitator[2] but rather upon the incumbent's incentive to use R&D strategically to deter entry. We show that innovation can indeed be entry-deterring, but in a long-run sense: whereas each new product introduction induces the imitator's temporary exit, permanent entry deterrence results from the imitator's expectation (based on observing the incumbent's R&D intensity) that new products will be introduced at a pace fast enough to make entry unprofitable at any time.

In our model, an innovating firm, called firm $D$, initially chooses the intensity of its R&D effort, proxied by the parameter $\lambda$ of a Poisson process driving the arrival of successive generations of an evolving product (like Intel's family of microprocessors). Firm $D$'s incentive to set $\lambda > 0$, at a cost $c(\lambda)$, stems from three basic forces. First, the rents that it can extract from any given generation shrink over time; thus, replacement is advantageous at some point. Second, the imitator's entry also reduces firm $D$'s rents. Introducing a new generation temporarily rids firm $D$ of its imitator, who will have to reenter afresh after a delay $\ell$ and at a cost $k$ of reverse-engineering. If the imitator were committed to be in the market no matter what, these would be firm $D$'s only two motivations for doing R&D. However, as the imitator must incur a sunk cost $k$ each time he reenters the market, firm $D$ can choose an R&D intensity so high that each generation's expected life (equal to $1/\lambda$) is just too short for the imitator to recoup his (sunk) entry cost. This will permanently deter the imitator's entry, providing firm $D$ with a third motivation for doing R&D.

Two fundamental features of our modelling effort, consonant with reality, are delays in imitation and firm $D$'s inability to revise its initial choice of R&D intensity. Imitation delays come in a variety of first-mover advantages including patents, causal ambiguity regarding the sources of efficiency (see Lippman and Rumelt, 1982), the ability to tie up the market in ancillary specialized assets (say via long-term contracts with suppliers), and other factors common to the industrial organization literature (*e.g.*, economies of scale, economies of scope, customer loyalty, customer switching costs,[3] reputation embodied in brand name capital[4] ). Additional lags leading to delay in imitation can originate from the time required for competitors to recognize the market success of the new innovation, the lead time required to reverse engineer the new product, bottlenecks in obtaining the use of specialized marketing and distribution channels, or delays in manufacturing (*e.g.,* the time required to learn how to manufacture a high quality product, acquire and ready specialized equipment

[2]This issue has been explored by Reinganum (1983) and is also considered by Cadot and Lippman (1996). A sequence of patent races is also analyzed in Denicolò (1997).

[3]Nintendo created very large customer switching costs by making their game cartridges incompatible with other game systems.

[4]Teece (1987, p. 208 - 209) points out that the IBM PC was a huge success even though its architecture was ordinary and its components were standard off-the-shelf parts available from outside vendors. One key to its success was "The reputation behind the letters I, B, M." Similarly, the G.D. Searle trade names NutraSweet and Equal for aspartame "will become essential assets when the patents on aspartame expire."

necessary for mass production, line up suppliers and distributors).

The second fundamental feature of our approach is the natural inflexibility in altering the firm's R&D intensity once it has been set. This inflexibility, which imparts commitment ability, appears in our model as an irreversible determination of $\lambda$ at time $t = 0$; it is equivalent to assuming that adjustment costs associated with changes in $\lambda$ are very large, or, in the words of Robert Reich (quoted in Cohen and Levinthal, 1994), that "once off the technological escalator it's difficult to get back on". This can be understood in view of three (complementary) explanatory factors. First, Argote, Beckman, and Epple (1990) found (p. 146) that "learning does not persist —knowledge acquired through production depreciates rapidly. [...] Recent experience is a significant predictor of learning while cumulative experience is not." As knowledge capital depreciates rapidly, variations in the rate of output are likely to entail efficiency costs; moreover, Argote *et al.* hypothesize that these costs are likely to be larger in contexts where employees are highly skilled and work is less standardized, such as R&D. Thus, their analysis suggests that fluctuations in R&D intensity generate significant inefficiencies; an illustration is provided by the diffulties encountered by NASA when it began rehiring five years after budget difficulties forced it to downsize in the early 1980s.

Second, information flows to and from the firm's R&D unit are critical factors in its capacity to innovate successfully. Knowledge generated by a firm's R&D department must permeate the entire organization; for instance, Quéré (1994) concluded from his case study of Thomson-CSF that "industrial applications fail because the skills and competencies in the basic research unit are not reflected elsewhere in the company" (p. 414). Researchers in the firm's R&D unit must also be thoroughly familiar with the firm's idiosyncratic needs; in the words of Cohen and Levinthal (p. 237), "to integrate complex technological knowledge successfully into the firm's activities, the firm requires an internal staff of technologists and scientists who are both competent in their fields and familiar with the firm's idiosyncratic needs and capabilities." Such familiarity comes in tandem with the spiral career path: internal job rotation and long tenure within the firm.

Third, a stable R&D department gives the firm the ability to rapidly absorb knowledge created elsewhere. Quéré (1994) observes that Thomson-CSF's basic research unit was seen as "a sort of company insurance [...] a pool of skills facilitating the access to new technological competencies." Together, these three arguments strongly suggest that a stable R&D force, one that is capable both of generating and absorbing knowledge, is a critical factor in a firm's ability to innovate successfully. Indeed, Wakasugi (1992) argues that the success of technological innovation in Japan, especially in electronics, is attributable to the lifelong employment and extensive job rotation policies practiced by Japanese firms.

We now turn to a model of repeated innovation and imitation. Section 2 sets up the model and derives basic results for the case where the imitator is committed to be in the market. Section 3 considers a simultaneous entry game and a sequential entry game. Section 4 concludes.

# 2 Repeated Innovation and Delays to Imitation

At time $t = 0$, an innovating firm, called firm $D$, chooses (once and for all) an R&D intensity level $\lambda$; $\lambda$ is a surrogate for the size of its R&D department. Once established, firm $D$'s R&D department produces a stream of new generations of an evolving product; the interarrival times between generations are distributed exponentially with parameter $\lambda$. Thus, innovation follows a Poisson process whose parameter is determined endogenously by firm $D$'s initial decision. An R&D department of size $\lambda$ entails, for firm $D$, a flow cost $c(\lambda)$. The function $c$ is increasing, convex, and continuouslly differentiable; moreover, we assume that $c(0) = 0$.

Each new generation renders the previous one obsolete (so sales of the old generation fall to zero as soon as the new generation is introduced) and is initially protected against imitation by a delay of fixed duration $\ell$. Upon discovery at time $t$, a new generation is costlessly brought to the market and generates monopoly rents $r_m$; from then on, rents decay exponentially at rate $\beta$ under the effect of market saturation.[5] At time $t + \ell$, an imitator enters the market and reduces firm $D$'s rents from $r_m e^{-\beta\ell}$ to $r_c e^{-\beta\ell}$ (with $r_c < r_m$) also collecting $r_c e^{-\beta\ell}$ for himself. After the imitator's entry, both rents continue decaying at rate $\beta$. Thus, as long as the generation introduced at $t$ is not superseded by a newer one, firm $D$'s rents at time $\tau$ are equal to $r_m e^{-\beta(\tau-t)}$ if $t < \tau \leq t+\ell$, and $r_c e^{-\beta(\tau-t)}$ if $\tau > t+\ell$. All costs and rents are discounted at rate $\alpha$.

We say that the $i^{th}$ 'cycle' begins with the introduction of the $i^{th}$ generation and ends with the introduction of the $i + 1^{st}$ generation. The expected discounted cycle length $\gamma$ satisfies $\gamma \equiv Ee^{-\alpha\tau} = \lambda/(\alpha+\lambda)$. Define $a \equiv \alpha+\beta$, let $r$ be firm $D$'s expected discounted revenue during a cycle, and $R$ its expected discounted revenue over the infinite horizon, so that

$$\begin{aligned} r &= E\left[\int_0^{\min\{\tau,\ell\}} r_m e^{-as}\, ds\right] + E\left[\int_\ell^{\max\{\tau,\ell\}} r_c e^{-as}\, ds\right] \\ &= \left[r_m - (r_m - r_c)e^{-(a+\lambda)\ell}\right]/(a+\lambda) \end{aligned}$$

and

$$R = r\gamma + r\gamma^2 + \cdots = r\gamma/(1-\gamma) = \lambda r/\alpha.$$

Firm $D$'s net expected discounted profit over an infinite horizon, $\pi_D$, satisfies

$$\pi_D = R - \frac{c(\lambda)}{\alpha} = \left[\frac{\lambda}{\alpha(a+\lambda)}\right]\left[r_m - (r_m - r_c)e^{-(a+\lambda)\ell}\right] - \frac{c(\lambda)}{\alpha}. \tag{1}$$

[5] We ignore intertemporal pricing issues [see Bulow (1982), Stokey (1981), Waldman (1993)].

The first-order condition is

$$\frac{1}{a+\lambda}\left[\frac{ar_m}{a+\lambda}+\left(\lambda\ell-\frac{a}{a+\lambda}\right)(r_m-r_c)e^{-(a+\lambda)\ell}\right]=c'(\lambda), \tag{2}$$

and the second-order condition holds. Let $\lambda_{in}(\ell)$ denote the (unique) solution of (2). Under the second-order condition, the effect of a change in the delay $\ell$ on optimal R&D effort $\lambda_{in}(\ell)$ is given by the sign of the cross-partial derivative of $\pi_D$ with respect to $\lambda$ and $\ell$. Straightforward calculations produce $\partial^2\pi_D/\partial\lambda\partial\ell = (1-\ell\lambda)(r_m - r_c)e^{-(a+\lambda)\ell}/\alpha$. Thus, $\lambda_{in}(\ell)$ satisfies

$$d\lambda_{in}/d\ell \geq 0 \quad \text{if and only if} \quad \ell\lambda_{in}(\ell) \leq 1. \tag{3}$$

A useful benchmark is the optimal level $\lambda_{out}$ of firm $D$'s R&D effort when there is no imitator. Define $\lambda_{out}$ by $\lambda_{out} \equiv \lim_{\ell\to\infty} \lambda_{in}(\ell)$. Observe that, as noted in Cadot and Lippman (1996), there exists a critical value of $\ell$ —call it $\ell_0$— such that whenever $\ell > \ell_0$, $\lambda_{in}$ is decreasing in $\ell$. That is, in spite of the improved appropriability of the return to innovations that a longer imitation delay confers, firm $D$ chooses to *reduce* its innovative effort as this delay gets longer. The reason is that imitation acts as a spur on firm $D$'s innovative effort, inducing it to choose a higher value of $\lambda$ than it would if it were a monopoly (this can be seen from the fact that $\lambda_{in}$ converges to $\lambda_{out}$ from above). When the imitation delay is long enough, this "competitive motivation" to innovate weakens, leading to lower values of $\lambda_{in}$.

Such a competitive motivation is different from entry deterrence, as the introduction of a new generation rids firm $D$ of its imitator only temporarily. In the next section, we consider whether firm $D$ can be induced to choose a value of $\lambda$ so high as to deter imitator entry altogether.

# 3 Endogenous Imitator Entry

Suppose now that the imitator faces an entry decision at time $t=0$, and that the cost of "reverse-engineering" is $k$ per product imitated. Clearly, the imitator's decision will be affected by the remaining length $\tau-\ell$ of the product cycle over which the imitation cost $k$ can be recouped. As the innovator understands this channel of influence on the imitator's entry decision, the obvious question is whether the possibility of deterring the imitator from entering can induce the developer to overinvest in R&D. Proposition 2 (in section 3.2) demonstrates that overinvestment can occur. However, the imitator's lack of commitment can also lead to a *reduced* level of innovative activity for some values of the delay $\ell$. We consider two games where the innovator chooses $\lambda$ while the imitator chooses *in* or *out*. If the imitator selects the strategy $q$ from his strategy space $[0,1]$, he has selected the action *in* with probability $q$ and *out* with probability $1-q$. When $q=1$ [$q=0$], we shall say that he has selected *in* [*out*].

Using the same reasoning as in section 2, the imitator's expected discounted profit $\pi_I$ over one cycle[6] is given by

$$\begin{aligned}\pi_I(\lambda;\ell) &= E\left[\int_{\ell}^{\max\{\tau,\ell\}} r_I e^{-as}\,ds - ke^{-\alpha\ell}\right] \\ &= r_I e^{-(a+\lambda)\ell}/(a+\lambda) \;-\; ke^{-(\alpha+\lambda)\ell}, \qquad (4)\end{aligned}$$

where $r_I$ is the imitator's rate of profit while selling in the market. Define $\lambda_c(\ell)$ by $\lambda_c(\ell) \equiv (r_I/k)e^{-\beta\ell} - \alpha - \beta$ (see figure 1a). By construction, $\pi_I[\lambda_c(\ell);\ell] \equiv 0$: $\lambda_c$ is the imitator's zero-profit curve. When the developer's rate $\lambda$ of innovative activity exceeds $\lambda_c(\ell)$, the imitator's expected profit is strictly negative and he chooses not to enter. When the inequality is reversed, he enters. The first game has simultaneous decisions; the second is a Stackelberg game in which the developer moves first.

## 3.1 Simultaneous Game

Let $\Lambda(q;\ell)$ and $Q(\lambda;\ell)$ denote, respectively, the developer's and the imitator's best response correspondences, and let $\Lambda^*(\ell)$ and $Q^*(\ell)$ denote the (set of) Nash equilibrium rate of innovation and entry status (they need not be unique). Proposition 1 shows that for each $\ell$ 'the' equilibrium rate $\Lambda^*(\ell)$ of innovative activity is restricted to $\lambda_{in}(\ell)$, $\lambda_{out}$, or $\lambda_c(\ell)$ when the latter lies between $\lambda_{in}(\ell)$ and $\lambda_{out}$. Let $q(\ell)$ satisfy equation (5) in the appendix.

**Proposition 1** *In the simultaneous entry game with $k > 0$, the following is an exhaustive description of all Nash equilibria:*
*(i) if $\lambda_c(\ell) < \lambda_{in}(\ell) < \lambda_{out}$, then $\langle\lambda_{out}, out\rangle$ is the unique equilibrium;*
*(ii) if $\lambda_c(\ell) < \lambda_{out} < \lambda_{in}(\ell)$, then $\langle\lambda_{out}, out\rangle$ is the unique equilibrium;*
*(iii) if $\lambda_c(\ell) > \max\{\lambda_{in}(\ell), \lambda_{out}\}$, then $\langle\lambda_{in}(\ell), in\rangle$ is the unique equilibrium;*
*(iv) if $\lambda_{in}(\ell) > \lambda_c(\ell) > \lambda_{out}$, then $\langle\lambda_c(\ell), q(\ell)\rangle$ is the unique equilibrium.*
*(v) if $\lambda_{out} \geq \lambda_c(\ell) \geq \lambda_{in}(\ell)$, then the game has three equilibria: $\langle\lambda_{in}(\ell), in\rangle$, $\langle\lambda_{out}, out\rangle$, and $\langle\lambda_c(\ell), q(\ell)\rangle$.*

**Proof** See appendix. □

FIGURES 1A AND 1B HERE

Notice that there is no overinvestment in the simultaneous game; that is, there is no $\ell$ such that $\Lambda^*(\ell)$ exceeds both $\lambda_{in}(\ell)$ and $\lambda_{out}$. Proposition 1 states that when the imitator faces a positive imitation cost, the possibility of keeping the imitator *permanently* out of the market (rather than for only one product cycle) constitutes

[6] The imitator's discounted profit over the infinite horizon is simply $\lambda\pi_I/\alpha$. Thus, it suffices to examine $\pi_I$ in order to determine the imitator's action.

a fourth force, distinct from the three forces identified in section 2, affecting firm $D$'s incentive to innovate. This fourth force affects the market outcome in three ways.

First, in region $(i)$, where $\lambda_c(\ell) < \lambda_{in}(\ell) < \lambda_{out}$, in order to keep the imitator out the developer chooses a higher rate of innovation than he would if the imitator were committed to being in the market (see figure 1a, where the thick line represents firm $D$'s equilibrium choice of $\lambda$). Strategic entry deterrence also happens in one of the three equilibria of region $(v)$. Second, an *increase* in the imitation delay $\ell$ can cause $\Lambda^*$ to decrease in a region of $\ell$ where $\lambda_{in}$ is increasing (in figure 1b, this is the region where $\ell_2 < \ell < \ell_3$). Third, when the imitation delay $\ell$ is at a sufficiently high level (region $(ii)$, i.e. $\ell > \ell_0$ in figure 1a and $\ell > \ell_3$ in figure 1b), the non-committed imitator chooses to stay out, relieving firm $D$ from the competitive pressure of imitation; as a result, the rate of innovation is lower than in the committed-imitator case. The reason is simple: when the imitation delay is longer than a certain critical value (namely $\ell_0$), the presence of a committed-imitator provides a *positive* incentive to innovate. Therefore, when the non-committed imitator chooses to stay out, firm $D$ *reduces* its innovative effort compared to the committed-imitator case. In sum, strategic interaction between the developer and a non-committed imitator in a simultaneous game affects the incentive to innovate, but it does so in a non-monotone way.

## 3.2 Sequential Game

In the sequential game the developer moves first by choosing $\lambda$. After observing $\lambda$,[7] and cognizant of the reverse-engineering cost $k$ per product, the imitator decides whether or not to enter.[8] If $\lambda_c(0) > \lambda_{out}$, we obtain, for some values of $\ell$, a new equilibrium which was absent from the simultaneous game, namely $\langle \lambda_c(\ell), out\rangle$. Proposition 2 states that there exist critical regions of $\ell$ in which $\langle \lambda_c(\ell), out\rangle$ is the unique equilibrium —and it entails 'overinvestment'.

**Proposition 2** *Consider the sequential entry game with $k > 0$. If $\lambda_c(0) \leq \lambda_{out}$, the unique equilibrium of the game is $\langle \lambda_{out}, out\rangle$ for each $\ell$. If $\lambda_c(0) > \lambda_{out}$, then the equilibria of the game vary as follows (see figure 2):*
*(i) $\langle \lambda_{out}, out\rangle$ when $\lambda_c(\ell) < \lambda_{out}$,*
*(ii) $\langle \lambda_c(\ell), out\rangle$ when $\lambda_{out}(\ell) < \lambda_c(\ell) < \lambda_{in}$,*
*(iii) either $\langle \lambda_{in}(\ell), in\rangle$ or $\langle \lambda_c(\ell), out\rangle$ when $\lambda_c(\ell) > \max\{\lambda_{out}, \lambda_{in}(\ell)\}$.*

*Moreover, there exists at least one interval $(a, b)$ such that $\Lambda^*(\ell) > \max\{\lambda_{in}(\ell), \lambda_{out}\}$*

[7] In regard to the entrant's knowledge of $\lambda$, Cohen and Levinthal (1994, p. 228) remark that "the incumbent's endogenous expectations of future technical advances diffuse to the entrant." This diffusion of the incumbent's expectations provides some support for the sequential model *vis-à-vis* the simultaneous model.

[8] In a continuous-time version of this game in which the rate $\lambda$ is selected at each moment in time, the equilibrium we obtain in the game in which the decision is made once and for all remains an equilibrium in the more complicated game.

*for* $a < \ell < b$.

**Proof** See appendix. □

FIGURE 2 HERE

Thus, in a sequential game, strategic entry deterrence can induce the developer to choose a rate of innovation that is higher than the maximum he would ever choose with a committed imitator, illustrating Cohen and Levinthal's remark (1994, p. 228) that "competition may lead to greater levels of investment as the incumbent makes strategic investments to dampen the entrant's investment incentives". It is not particularly surprising that this overinvestment, a form of predation, occurs in the sequential game but not in the simultaneous game, for the sequentiality bestows upon the developer the ability to precommit.[9]

The reason for choosing a larger rate of innovation than would be the case with a committed imitator can be made clear by using an analogy with investment in plant capacity. Interpret $\lambda$, the rate of innovative intensity chosen by the innovator at time $t = 0$, as an investment in 'innovative capacity'. (This interpretation is consistent with the idea that $\lambda$ is a surrogate for the size of firm $D$'s R&D department.) Following Tirole (1989, p. 325), let us define 'overinvestment' in the sequential game as a level of investment in excess of that chosen by the innovator in the equilibrium of the simultaneous game. In ranges of $\ell$ where the simultaneous game has multiple equilibria, we take the maximum value of $\Lambda^*(\ell)$ as the benchmark. Using this definition, there is overinvestment in the sequential game for $a < \ell < b$. To see this, notice, by inspection of figure 2 or of equation (4), that in a neighborhood of $\pi_I = 0$, $\partial\pi_I/\partial\lambda < 0$. Suppose that, were the innovator to accommodate entry, the optimal value of $\lambda$ would be slightly lower than $\lambda_c(\ell)$, the critical value of $\lambda$ which makes the imitator's profits zero. By raising $\lambda$ slightly, to $\lambda_c(\ell)$, the innovator can then reduce the attractiveness of entry by just enough to keep the imitator out. Proposition 2 states that, when $a < \ell < b$, the loss due to a higher-than-optimal level of $\lambda$ (the 'overinvestment') is more than compensated by the benefit of keeping the imitator out. In this range of $\ell$, the innovator's strategy can be loosely compared to what Fudenberg and Tirole (1984) called a "top dog" strategy.[10]

[9] Apart from a large and early literature on entry deterrence, an important early example of precommitment is the incumbent's overinvestment in plant capacity as analyzed in Spence (1977) and Dixit (1979, 1980). See Shapiro (1989) for an extensive list of commitment strategies.

[10] In a standard two-stage capacity-production game, one firm's choice of a larger capacity has the effect of shifting second-stage reaction functions in such a way as to reduce the other firm's equilibrium output (and, consequently, its incentive to enter). Here, the innovator's choice of a higher $\lambda$ does not affect the imitator's output *rate*, but it reduces the expected *length* of the spell during which the imitator will be on the market. This may lead to entry deterrence, as the imitator anticipates that he will be able to recoup his sunk cost of imitation $k$ over a smaller cumulative output.

### 3.3 Imitation and Market Saturation

We now consider the effect of changes in the rate $\beta$ of market saturation on the equilibrium rate of innovation in the simultaneous game with $\ell = 0$ (*i.e.*, no barriers to imitation). The assumption $\ell = 0$ simplifies the algebra. Proposition 3 shows that faster saturation can, locally, lead to an increase in the developer's equilibrium profit.

Evaluating (2) at $\ell = 0$ and substituting $\alpha+\beta$ for $a$ yields the first-order conditions $(\alpha+\beta)r_c = (\alpha+\beta+\lambda)^2 c'(\lambda)$ if the imitator is *in* and $(\alpha+\beta)r_m = (\alpha+\beta+\lambda)^2 c'(\lambda)$ if he is *out*. Let $\lambda_{in}(\beta)$ and $\lambda_{out}(\beta)$ denote the solution to these two equations, respectively. It is easily seen that both $\lambda_{in}(\beta)$ and $\lambda_{out}(\beta)$ are non-monotone functions of $\beta$ and that $\lambda_{in}(\beta) < \lambda_{out}(\beta)$. This non-monotonicity stems from the countervailing impacts of a change in $\beta$ on the appropriability and replacement effects. When $\beta = 0$, fighting imitation is the only motivation for product replacement. For $\beta > 0$, as sales of each generation shrink over time, replacement becomes necessary even without imitation; but each new generation's introduction cannibalizes sales of the previous one, dampening firm $D$'s incentive to innovate. As $\beta$ increases, this cannibalization effect weakens, inducing firm $D$ to set $\lambda$ at a higher level. On the other hand, as $\beta$ increases, the expected return on the new generation is reduced, because its sales will shrink faster. This appropriability effect induces firm $D$ to set $\lambda$ at a lower level. For small values of $\beta$, the cannibalization effect (sometimes called a 'replacement effect') dominates, so that $\lambda$ is an increasing function of $\beta$; but for large values of $\beta$, the appropriability effect dominates, so that $\lambda$ is a decreasing function of $\beta$. As in previous sections, the optimal value of $\lambda$ is affected by the imitator's entry status and is denoted by $\lambda_{in}$ if the imitator is *in* or $\lambda_{out}$ if the imitator is out (see figure 3). It is clear from (4) that the imitator's zero-profit curve in $(\beta, \lambda)$ space is given by $\lambda_c(\beta) = (r_I/k) - \alpha - \beta$.

FIGURE 3 HERE

**Proposition 3** *In a simultaneous game with positive imitation cost ($k > 0$) and no barriers to imitation ($\ell = 0$), there exists at least one critical value $\tilde{\beta}$ of $\beta$ such that, for $\epsilon$ small, $\pi_D[\Lambda^*(\tilde{\beta}+\epsilon), Q^*(\tilde{\beta}+\epsilon), \tilde{\beta}+\epsilon] > \pi_D[\Lambda^*(\tilde{\beta}), Q^*(\tilde{\beta}), \tilde{\beta}]$.*

**Proof** See appendix. □

The intuition of Proposition 3 is closely related to that of Proposition 1. When $\beta$ is small enough, the unique equilibrium is $\langle \lambda_{in}(\beta), in \rangle$. As $\beta$ increases to a first critical point $\beta_-$, two additional equilibria appear: $\langle \lambda_{out}(\beta), out \rangle$ and a mixed-strategy equilibrium similar to the one we constructed in Proposition 1 (see appendix). As $\beta$ increases further past a second critical point $\beta_+$ ($> \beta_-$), the only equilibrium that remains is $\langle \lambda_{out}, out \rangle$. Therefore, as $\beta$ increases, at some point between $\beta_-$ and $\beta_+$, the equilibrium level of innovation has to jump from $\lambda_{in}$ to $\lambda_{out}$. This upward jump in $\lambda$, associated with the imitator's change of status (from *in* to *out*), increases the developer's equilibrium profit. Although a smaller market (equivalently, large $\beta$) always reduces the developer's profit given the status of the imitator (*in* or *out*), in the simultaneous game a large value of $\beta$ can act as a barrier to imitation. When this barrier is sufficient to preclude the imitator's entry, an increase in $\beta$ plays to the advantage of the developer by enabling him to operate as a monopoly.

Proposition 3 has interesting implications for the dynamics of declining industries. Suppose that the demand for a given product is shrinking over time, in spite of the periodic introduction of new designs; that is, $\beta$ is itself increasing over time. Proposition 3 suggests that as the imitator exits the industry before firm $D$, the latter's profit may temporarily recover. It is even possible that, as a result of the imitator's exit, firm $D$ increases its pace of innovation (recall that the presence of an imitator works here to *reduce* firm $D$'s incentive to innovate, because $\ell = 0$ by assumption). But this increase in profitability and innovation would be but a short-lived remission in the industry's declining fortunes.

# 4 Concluding remarks

We showed how the innovator's capacity to introduce new generations of an innovative product with (stochastically) short interarrival times can act as a commitment and thereby result in strategic entry deterrence. If the imitator's entry decision is simultaneous with the innovator's R&D decision, a sufficiently long imitation delay results in what Bain (1956) called 'blockaded entry'. In this case, the innovator's effort is at its monopoly level and is strictly less than what it would be with a committed imitator. The level of innovative effort in the simultaneous game provides a benchmark against which we define 'overinvestment' in the sequential game where the imitator decides whether or not to enter after having observed the innovator's R&D decision. The perfect equilibrium of a sequential game can entail overinvestment (see Proposition 2). The attractiveness of overinvestment in R&D for the innovator derives from the fact that more innovative capacity reduces the average length of time over which the imitator can recoup his sunk costs, thereby depressing the expected profitability of entry. The presence of a potential imitator can increase the equilibrium pace of innovation even in ranges of $\ell$ where the equilibrium outcome is entry deterrence rather than accommodation.

What does our model have to say about real-life industry dynamics? As the imitator is precluded from doing R&D, we rule out a discussion of how frequently firm $D$ might be unseated from its incumbency position. Instead, our objective is to show how the imitator's entry decision can be affected by firm $D$'s R&D intensity. Although our framework is, arguably, applicable to a fairly wide range of industries, its assumptions fit particularly well the fashion good industry, where original design manufacturers use frequent product-line renewal to fight market saturation and the entry of imitators, most of whom have little original design capability. Our analysis suggests several observations. First, provided that the imitation delay is sufficiently long, the presence of imitators contributes, perhaps in a key way, to the extremely fast pace of product redesign that is the industry's hallmark. High-end clothing manufacturers strategically shorten the cycle to the point where entry becomes unprofitable; they can succeed in doing so by committing significant resources to design and by producing close to the market. Second, suppose that the production of imitations were to move to countries with poor export infrastructures, resulting in longer imitation delays. As this would enhance the ability of original-design manufacturers to appropriate the return from design innovation, the conventional wisdom would suggest that the pace of innovation should increase. However, in our framework, the effect would be just the opposite: the pace of innovation would slow down.

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# 5 Appendix

**Proof of Proposition 1** Let $L_{out} = \{\ell : \lambda_{out} \geq \lambda_c(\ell)\}$, $L_{in} = \{\ell : \lambda_{in}(\ell) \leq \lambda_c(\ell)\}$, $\ell_2 = \min L_{out}$, so $\lambda_c(\ell_2) = \lambda_{out}$, and $\ell_3 = \min \{\ell : \lambda_{in}(\ell) \geq \lambda_c(\ell)\}$. Finally, let $g_0(\lambda, \ell)$ and $g_1(\lambda, \ell)$ stand for $\partial\pi_D(\lambda, q, \ell)/\partial\lambda$ evaluated at $q = 0$ and $q = 1$, respectively. Fix $\ell \in L_{in}$ so that $\lambda_{in}(\ell) \leq \lambda_c(\ell)$. Clearly, $\langle\lambda_{in}(\ell), 1\rangle$ is an equilibrium. We claim it is unique in $L_{in}\backslash L_{out}$. To see this, consider any $\lambda > \lambda_c(\ell)$. Then $Q(\lambda; \ell) = 0$ so $\Lambda(0; \ell) = \lambda_{out} \leq \lambda_c(\ell)$, a contradiction.

If $\ell \in L_{out}$, $\lambda_{out} \geq \lambda_c(\ell)$ so by the argument of the previous paragraph, $\langle\lambda_{out}, 0\rangle$ is an equilibrium and it is unique in $L_{out}\backslash L_{in}$. If $\ell \in L_{out} \cap L_{in}$, the game has three equilibria: $\langle\lambda_{in}(\ell), 1\rangle$, $\langle\lambda_{out}, 0\rangle$, and a mixed-strategy equilibrium $\langle\lambda_c(\ell), q(\ell)\rangle$. In order to construct the mixed-strategy equilibrium, let $q(\ell)$ satisfy

$$q\, g_1[\lambda_c(\ell), \ell)] + (1 - q)\, g_0[\lambda_c(\ell), \ell] = 0. \tag{5}$$

Equation (5) is the innovator's first-order condition when the imitator chooses *in* with probability $q$ and the innovator's best response $\lambda$ is $\lambda_c(\ell)$. If such a $q(\ell)$ exists, $\Lambda(q(\ell); \ell) = \lambda_c(\ell)$ and $Q[\lambda_c(\ell); \ell] = q(\ell)$, as $\pi_I[\lambda_c(\ell), 1, \ell] = \pi_I[\lambda_c(\ell), 0, \ell] = 0$ implies that $q(\ell)$ is a weak best response to $\lambda_c(\ell)$. We need to show that $q(\ell)$ exists and is in $[0, 1]$. If $L_{out} \cap L_{in} \neq \emptyset$, $\ell_2 < \ell_3$, so $\ell \in L_{out} \cap L_{in} \Leftrightarrow \ell_2 \leq \ell \leq \ell_3$. Suppose that $\ell = \ell_3$, then $\lambda_c(\ell) = \lambda_{in}(\ell)$ by continuity of these functions. As $g_1[\lambda_{in}(\ell), \ell] \equiv 0$, it follows that $g_1[\lambda_c(\ell_3), \ell_3] = 0$; so, setting $q(\ell_3) = 1$ satisfies (5). Suppose now that $\ell = \ell_2$, $\lambda_c(\ell) = \lambda_{out}$ so by a similar argument, setting $q(\ell_2) = 0$ satisfies (5). Next, fix any $\ell \in (\ell_2, \ell_3)$. By monotonicity of $\lambda_c(\ell)$, $\lambda_{in}(\ell) < \lambda_c(\ell) < \lambda_{out}$. The last inequality implies that, under the second-order condition, $g_0[\lambda_c(\ell), \ell] > 0$. The first inequality similarly implies that $g_1[\lambda_c(\ell), \ell] < 0$. So $q(\ell)\, g_1[\lambda_c(\ell), \ell] + [1 - q(\ell)]\, g_0[\lambda_c(\ell), \ell] = 0 \Leftrightarrow q(\ell) \in (0, 1)$.

Finally, suppose $\ell_3 < \ell_2$ so $L \equiv R_+\backslash(L_{out} \cup L_{in})$ is not empty, $\ell_3 = \inf L$, $\ell_2 = \sup L$, and $\ell \in L$ implies that $\lambda_{out} < \lambda_c(\ell) < \lambda_{in}(\ell)$. Then $\langle\lambda_c(\ell), q(\ell)\rangle$ is the unique equilibrium of the game. We deomonstrate this as follows. Monotonicity of $\lambda_c(\ell)$ implies that $\Lambda^*(\ell_3) = \lambda_c(\ell_3)$ and $\Lambda^*(\ell_2) = \lambda_c(\ell_2)$. Then $q(\ell_3) = 1$ and $q(\ell_2) = 0$ satisfy (5). Next, fix any $\ell \in (\ell_3, \ell_2)$. By the second-order condition, $g_1[\lambda_c(\ell), \ell] > 0$ and $g_0[\lambda_c(\ell), \ell] < 0$; so $q(\ell)\, g_1[\lambda_c(\ell), \ell] + [1 - q(\ell)]\, g_0[\lambda_c(\ell), \ell] = 0$ implies that $q(\ell) \in (0, 1)$. For uniqueness, consider any $\lambda > \lambda_c(\ell)$. Then $Q(\lambda, \ell) = 0$, but $\Lambda(0, \ell) = \lambda_{out} < \lambda_c(\ell)$, a contradiction; a similar argument holds for any $\lambda < \lambda_c(\ell)$. □

**Proof of Proposition 2** The game is solved by backward induction, starting with firm I (the imitator). As noted at the beginning of Section 3.2, in order to avoid non-existence of equilibrium, we assume firm I plays *out* when $\lambda = \lambda_c(\ell)$. Thus, firm I plays *in* if and only if $\lambda < \lambda_c(\ell)$. We now examine the three cases of Proposition 2.

(i) $\lambda_c(\ell) < \lambda_{out}$

For $\lambda \neq \lambda_{out}$, $\pi_D(\lambda_{out}, 0, \ell) > \pi_D(\lambda, 0, \ell) > \pi_D(\lambda, 1, \ell)$, so firm D sets $\lambda = \lambda_{out}$. The imitator plays *out* in response to $\lambda_{out}$; thus, $\langle\lambda_{out}, 0\rangle$ is the unique equilibrium.

(ii) $\lambda_{out} < \lambda_c(\ell) < \lambda_{in}(\ell)$

Observe that global concavity of $\pi_D$ in $\lambda$ (the second-order condition) implies $\partial\pi_D(\lambda, 0, \ell)/\partial\lambda < 0$ for all $\lambda > \lambda_{out}$. As $\lambda_c(\ell) > \lambda_{out}$, it follows that $\lambda_c(\ell)$ maximizes $\pi_D(\lambda, 0, \ell)$ on $[\lambda_c(\ell), \infty)$.

Consequently, if firm D sets $\lambda > \lambda_c(\ell)$, then I plays *out* so that $\pi_D[\lambda_c(\ell), 0, \ ell] > \pi_D[\lambda, 0, \ell]$. On the other hand, if firm D sets $\lambda < \lambda_c(\ell)$, then I plays *in* so that $\pi_D[\lambda_c(\ell), 0, \ell] > \pi_D[\lambda_{in}, 0, \ell] > \pi_D[\lambda_{in}, 1, \ell] > \pi_D[\lambda, 1, \ell]$, where the first inequality follows from $\lambda_{in}(\ell) > \lambda_c(\ell)$ and the fact that $\lambda_c(\ell)$ maximizes $\pi_D(\lambda, 0, \ell)$ on $[\lambda_c(\ell), \infty)$. Thus, firm D necessarily plays $\lambda_c(\ell)$, and firm I responds by playing *out*.

(iii) $\lambda_c(\ell) > \max\{\lambda_{in}(\ell), \lambda_{out}\}$

Define $\tilde{\ell} = \min\{\ell_2, \ell_3\}$ and $\delta(\ell) = \pi_D[\lambda_c(\ell), 0, \ell] - \pi_D[\lambda_{in}(\ell), 1, \ell]$, where $\ell_2$ and $\ell_3$ are defined in the proof of Proposition 1. We claim that $\delta(\tilde{\ell}) > 0$. To see this, suppose first that $\ell_2 < \ell_3$ as illustrated in Figure 1a. Then $\pi_D[\lambda_{in}(\ell_2), 1, \ell_2] < \pi_D[\lambda_{in}(\ell_2), 0, \ell_2] \leq \pi_D[\lambda_{out}, 0, \ell_2] = \pi_D[\lambda_c(\ell_2), 0, \ell_2]$, so $\delta(\ell_2) > 0$. When $\ell_3 < \ell_2$, the result is immediate because $\lambda_c(\ell_3) = \lambda_{in}(\ell_3)$ as illustrated in Figure 1b.

From (2) and the definition of $\lambda_c(\cdot)$, $\lambda_{in}(\ell)$ and $\lambda_c(\ell)$ are both continuous in $\ell$. Coupling this fact with (1) reveals that $\pi_D(\lambda, q, \ell)$ is continuous in $\lambda$ and $\ell$ for $q = 0$ and $q = 1$. Consequently, $\pi_D[\lambda_{in}(\ell), 1, \ell]$ and $\pi_D[\lambda_c(\ell), 0, \ell]$ are both continuous in $\ell$ so that $\delta(\ell)$ is also continuous in $\ell$. Therefore, $\delta(\tilde{\ell}) > 0$ ensures that there exists an $\epsilon > 0$ such that $\pi_D[\lambda_c(\ell), 0, \ell] > \pi_D[\lambda_{in}(\ell), 1, \ell]$ on the interval $(\tilde{\ell} - \epsilon, \tilde{\ell}) \equiv (a, b)$. And by the definition of $\tilde{\ell}$, $\lambda_{out} < \lambda_{in}(\ell) < \lambda_c(\ell)$ on $(a, b)$.

Fix $\ell$ in $(a, b)$. As argued in part (ii), $\pi_D(\lambda, 0, \ell)$ is decreasing on $[\lambda_c(\ell), \infty)$ so firm D never selects $\lambda > \lambda_c(\ell)$. For $\lambda < \lambda_c(\ell)$ we have $\pi_D[\lambda_c(\ell), 0, \ell] > \pi_D[\lambda_{in}(\ell), 1, \ell] \geq \pi_D[\lambda, 1, \ell]$. Hence, firm $D$ plays $\lambda_c(\ell)$ on $(a, b)$ as asserted.

When $\delta(\ell) = 0$, both $\langle \lambda_{in}(\ell), in \rangle$ and $\langle \lambda_c(\ell), out \rangle$ are equilibria. Similar arguments show that these are the only equilibria on $[0, \tilde{\ell}]$. □

**Proof of Proposition 3** Let $\beta_-$ and $\beta_+$ satisfy respectively $\lambda_{out}(\beta_-) = \lambda_c(\beta_-)$ and $\lambda_{in}(\beta_+) = \lambda_c(\beta_+)$. Consider $\beta$ such that $\langle \Lambda^\star(\beta), Q^\star(\beta) \rangle = \langle \lambda_{in}(\beta), 1 \rangle$ and $\langle \Lambda^\star(\beta + \epsilon), Q^\star(\beta + \epsilon) \rangle = \langle \lambda_{out}(\beta + \epsilon), 0 \rangle$ for any $\epsilon > 0$. As $\langle \lambda_{in}(\beta), 1 \rangle$ is the unique equilibrium to the left of $[\beta_-, \beta_+]$ and $\langle \lambda_{out}(\beta + \epsilon), 0 \rangle$ is the unique equilibrium to the right of $[\beta_-, \beta_+]$, $\beta$ exists and is in $[\beta_-, \beta_+]$. Now, notice that $\pi_D[\Lambda(1; \beta), Q[\lambda_{in}(\beta), \beta], \beta] = \pi_D[\Lambda(1; \beta), 1, \beta] < \pi_D[\Lambda(1; \beta), 0, \beta] \leq \pi_D[\Lambda(0; \beta), 0, \beta] = \pi_D[\Lambda(0; \beta), Q[\lambda_{out}(\beta), \beta], \beta]$. Next, observe that $\pi_D$ is continuous in $\lambda$ and $\beta$, and that $\lambda_{in}(\beta)$ and $\lambda_{out}(\beta)$ are continuous in $\beta$, so $\pi_D[\lambda_{in}(\beta), 1, \beta]$ and $\pi_D[\lambda_{out}(\beta), 0, \beta]$ are continuous in $\beta$. Therefore there exists an $\epsilon > 0$ such that $\pi_D[\Lambda^\star(\beta + \epsilon), Q^\star(\beta + \epsilon), \beta + \epsilon] > \pi_D[\lambda_{in}(\beta), Q^\star(\beta), \beta]$. □

**Figure 1a**

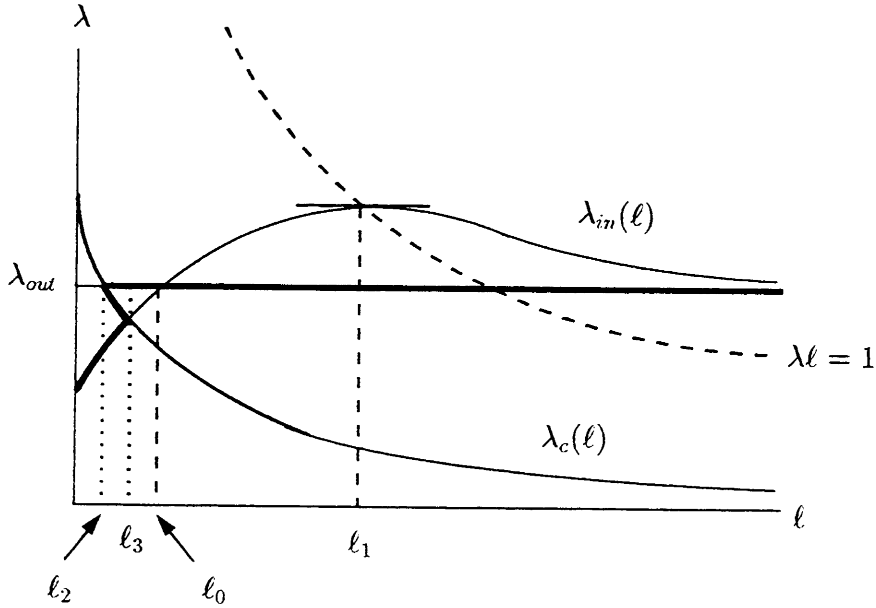


**Figure 1b**

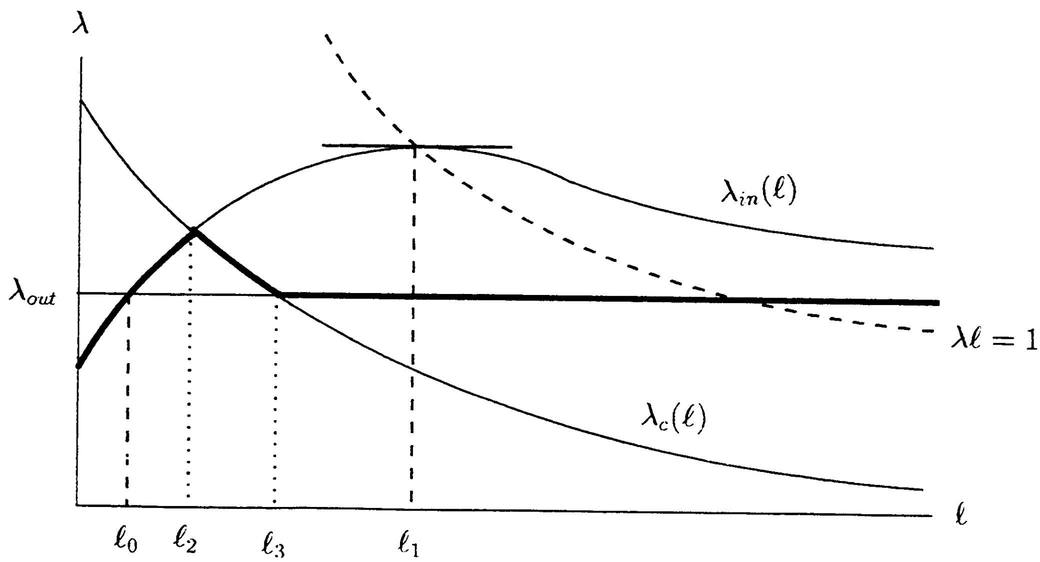

**Figure 2**

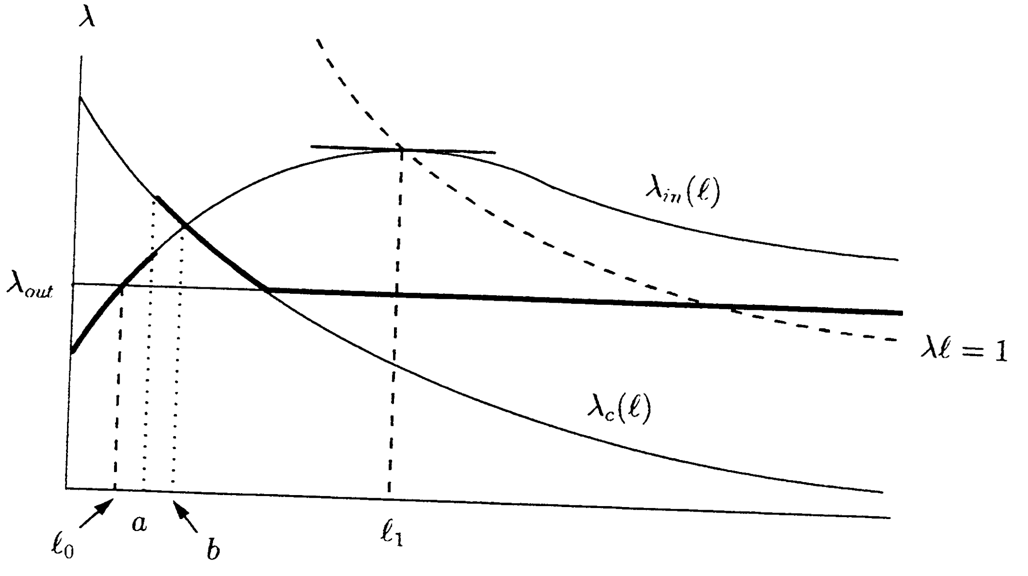


**Figure 3**