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SECOND-MOVER ADVANTAGE IN R&D INNOVATION AND IMITATION IN DYNAMIC OLOGOPOLY#

by

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1. INTRODUCTION

Partly reflecting a surge of business interests on technological advancements and partly reflecting developments in applied micro-economics as well as in Game theory, a bulk of theoretical studies on research and development (R&D for short) activities have appeared recently. Many of these studies are especially concerned with strategic aspects of R&D race: a natural trend if one considers R&D to be one of the key determinants of a market structure and/or of the success of a firm.

One stream of thought that emerged from these literature (e.g., Dasgupta and Stiglitz [1980], Gilbert and Newberry [1982]) emphasizes the role played by the first mover advantage. In dynamic games played to obtain an exclusive patent for new innovation, the first mover can often preempt its rival. For example, suppose both the incumbent monopolist and new entrant have the same R&D seed. That is, both can obtain an exclusive patent for new product which is a close substitute to the product being produced by the incumbent. In such a situation, the incumbent always preempts the entrant for, being the first mover to the market, incumbent has a larger incentive for the patent to keep its monopoly profit (see Gilbert and Newberry [1982] for more details.) Similarly, even if two firms are attempting to obtain an exclusive patent for identical new product, a firm which has accumulated even a slight edge in R&D capital can always preempt because of the cost advantage (see, for example, Fudenberg, Dasgupta, Stiglitz and Tirole [1982]).

According to this line of thought the incumbent of an industry, being the first mover, always carry its strategic advantage and R&D will make industries more concentrated. This result, often called "persistence of monopoly" or "ε-preemption" argument, provoked a series of criticisms. They are particularly concerned with the assumed "non-drastic" nature of innovation and neglected uncertainty associated with innovation. Incorporating these natures of innovation, firms that hold the first mover advantage may not preempt rivals. In other words, the first mover advantage is strategically important but sometimes not important enough to guarantee the persistence of monopoly or ε-preemption (see, e.g., Reinganum [1983] for more details).

In the world of R&D, however, sometimes the second mover advantage exists. Imitating rivals' products is often much easier than developing original products. Duplicating successful products mitigates risks associated with introduction of a new product to the market.

However, an explicit consideration of the second mover advantage in strategic models of R&D hardly exists. The purpose of this paper is to analyze the impact of the second mover advantage in dynamic games when strategic considerations play an important role. We contend that, in the actual rivalry on new products and other R&D activities, exclusive patenting usually assumed in the theoretical literature (including Gilbert-Newbery) does not correctly approximate the reality. Even if a product or a technology is protected by a patent, often times a firm can develop an alternative technology to get around the patent protection. This strategy is particularly important for large incumbents, for they can regain a large share even if small unknown entrants first capture the market.

We shall develop a game-theoretic model of R&D rivalry with a possibility of duplicating the rival's new product. A firm can invest enough resources in basic (or marketing) technology at the outset of the game so that it can develop an alternative technology that bypasses the rival's patent protection even if the rival obtains patent protection.

Alternatively, our assumption can be interpreted as a firm investing in marketing activity which enhances the firm's image in the market, so that even as a late-comer to the market it can still compete with the (potential) preempter successfully. Investing in resources for future duplication (hereafter duplication strategy) gives a second mover advantage to a firm because it can duplicate the rival's product and/or technology after the product turns out to be successful in the market.

Our main results are as follows:

(1) Even if an incumbent introduces a new product, entrants without their own R&D seeds is able to capture positive profit by duplicating a successful product. Thus, even if an incumbent firm invents a product first, there still exists new entry and innovation diffuses. In this sense, the first mover advantage may not exist.

(2) If two firms have the same R&D seed, the firm that has duplication possibility can preempt its rival who does not have the possibility. In this sense investing in duplication technology creates a first mover advantage, just because it will provide a second mover advantage.

(3) If two firms have the same R&D seed and both have the duplication possibility, the game of R&D may become a "game of waiting" and R&D investment may become socially insufficient. This is likely to happen when duplication is relatively inexpensive compared to self-invention.

The plan of the paper is as follows. In Section 2, our model is presented and different cases are classified. In Section 3, we define several important functions and classify the underlying parameter space. The equilibrium concept employed in the paper is defined and the first case is analyzed in Section 4. In Sections 5-7, other cases are analyzed, while

Section 8 is devoted to the interpretation of the earlier results. Section 9 concludes the paper. Some technical details are relegated to the Appendix.

2. MODEL

Suppose there is an idea of a new product which has not yet been introduced to the market. Transforming the idea into an actual product and introducing the product to the market requires both R&D cost and marketing cost. We shall call the aggregate of these two as "market introduction cost." Two firms, 1 and 2, are conceiving of a possibility to transform the idea into a new product for eventual introduction to the market. We shall assume that there are two ways of doing so: self-invention and duplication.

Self-invention requires invention capital of C_S at the outset (t=0) and market introduction (often called invention) cost f(t) at $t \geq 0$ depending on when invention takes place. Invention time t is a strategic variable. There is no uncertainty whether the invention will be successful and when it will take place, but there is uncertainty about consumers' judgements. We assume that, with probability 1-p, the product will be judged worthless by consumers. Only with probability p, the product will provide positive profit to the inventor. Once a firm invents and introduces the product to the market, it will be protected by the exclusive patent and the rival cannot duplicate it without using duplication technology.

Duplication requires duplication capital of C_D at the outset (t=0) and market introduction (often called duplication) cost d(t') at $t' \geq t \geq 0$ depending on when duplication takes place. Duplication (at t'), introduction of a perfect substitute to the market, takes place only after the rival invents the product (at t). Duplication date is also a strategic variable. Second mover advantage exits to a duplicator because it can wait until market introduction by the rival and duplicates only when the product is successful (i.e., success of the duplicator's product is always guaranteed.)

Committing to invention capital and/or duplication capital is also a strategic decision, and we shall analyze the implications of these decisions in Section 8. In the next five sections, we shall assume the cost for these capital have been sunk already.

For two market introduction cost functions, f(t) and d(t), we shall assume the following throughout the paper:

<A-1> For all $t > 0$, $f(t) > 0$, $f'(t) < 0$, $f''(t) > 0$, and

$$\lim_{t \to +0} f(t) = +\infty,\ \lim_{t \to \infty} f(t) = 0,\ \lim_{t \to +0} f'(t) = -\infty,\ \lim_{t \to \infty} f'(t) = 0.$$

<A-2> For all $t > 0$, $d(t) > 0$, $d'(t) < 0$, $d''(t) > 0$, and

$$\lim_{t \to +0} d(t) = +\infty,\ \lim_{t \to \infty} d(t) = 0,\ \lim_{t \to +0} d'(t) = -\infty,\ \lim_{t \to \infty} d'(t) = 0.$$

For simplicity of exposition, we further impose:

<A-3> There exists some $\beta > 0$ such that for all $t \geq 0$ $f(t) = \beta d(t)$.

Thus, β denotes the relative cost advantage in self-invention.

Suppose that firm $i \in \{1,2\}$ has invention capital, invents the product and finds the product well received by consumers: the case we shall refer to as i becoming a successful leader. The leader can receive profit from the market depending upon the rival's reaction. If the rival does not follow, either because it has no duplication capital or because of its choice, the leader will receive monopoly profit π_M from time t on indefinitely. If the rival introduces a perfect substitute using duplication technology, the leader and the rival will share the market and both will receive the same profit π_C ($\leqq \pi_M$) from the time when the follower introduced the product.

Suppose both firms have invention capital and simultaneously introduce the product (with each spending invention cost of f(t)): the case we shall refer to as the joint introduction. If the product turns out profitable, each will receive a perpetual flow of profit π_C as in the previous case.

Following Gilbert-Newbery [1982], we shall assume:

$$\langle A\text{-}4\rangle \qquad \pi_M \geqq 2\pi_C.$$

This is a natural consequence of the fact that the product introduced by duplication technology is a perfect substitute of the first product.

A firm may have invention capital only (the firm will be called a self-inventor; S), duplication capital only (called a duplicator; D) or both (called of general type; G). Depending upon which firm is of what type, there are six cases to consider (except mirror image case.)

(a) Both firms are self-inventors; Case S-S.

(b) Both firms are duplicators; Case D-D.

(c) Firm 1 is a self-inventor and 2 is a duplicator; Case S-D.

(d) Firm 1 is of general type and 2 is a self-inventor; Case G-S.

(e) Firm 1 is of general type and 2 is a duplicator; Case G-D.

(f) Both firms are of general type; Case G-G.

Obviously, Case D-D is not worthwhile investigating because a new product is never introduced. Similarly, case (e) is essentially identical to the case (c), for firm G never has a chance to use duplication technology. Thus, we shall consider four cases, S-S, S-D, G-S and G-G.

In order to facilitate the reader's understanding, we present the most general case of G-G in an "extensive form" in Figure 1. Figure 1 does not describe the timing of each move nor how the game evolves for those instants when neither player has active move. In this respect, it is not the correct extensive form representation of the game.

This case is classified into three subcases; (a) firm 1 introduces the product first, (b) firm 2 introduces first, (c) both introduce simultaneously.

(a) Firm 1 first introduces the product (firm 1 is the leader and firm 2 the follower): If the product is a success (the Nature R takes the branch S), then firm 2 has a choice of either introducing the substitute, i.e., duplicating the original product (choice "D"), or not duplicating and dropping out of the R&D race (choice "ND"). When firm 2 duplicates, both firms reach a final state denoted by (1-1). If it does not, they reach (1-2). When the product turns out to be a failure (the branch F) the game ends with (1-3).

(b) Firm 2 first introduces the product: The game is identical to (a) except that firms 1 and 2 reverse their roles.

(c) Both firms introduce the product simultaneously. Depending on whether the product is a success or a failure, the game ends at (J-S) or (J-F).

In the case G-S, essentially the same structure is obtained as in G-G except firm 2, which has not committed to the duplication capital, cannot choose strategy D. Hence final state (1-2) is no longer available. In the case of S-D or G-D, firm 2 cannot take any active move. Hence only branches that lead to (1-1), (1-2) and (1-3) matter. Finally, in the case of S-S, the game will be played in the same way as in Panel B except once a firm becomes the follower it can never duplicate.

In order to analyze the games described above, we shall use the concept of sub-game perfect equilibrium. This equilibrium concept in a dynamic context is best handled by the technique developed by Fudenberg-Tirole [1984]. For this, we shall develop functions L(t), F(t) and J(t) for each case. The function L(t) describes the expected (present discounted) payoff to a firm that introduces the product first (the leader) at t. We shall assume the leader will expect the rival's optimal reaction (whether or not to duplicate and when to duplicate) upon computing L(t). F(t) describes the level of payoff a firm (the follower) can obtain when its rival introduces the product first at time t. The follower will take account of its own optimal reaction upon computing this payoff. J(t) defines the payoff to a firm when two firm simultaneously introduces the product at t. These payoffs are the present discounted value evaluated at t=0 and commitment costs for duplication/invention capital, C_S and C_D, are excluded.

In order to define these functions, we shall also introduce three auxiliary functions M(t), D(t) and C(t) in the next section. Type of equilibrium in each case depends upon properties of L(t), F(t) and J(t). These properties depends upon the properties of M(t), C(t) and D(t) which, in turn, depends upon the values of parameters such as p, β, π_M, π_C. In the next section, we shall examine properties of these functions and classify the parameter space.

3. PARAMETRICAL CHARACTERIZATION OF CASE G-G

In order to formally define and analyze these functions, define two more functions:

$\Psi(t;a,b) := [(a/r) - bd(t)]e^{-rt}$, and

$T(a/b) := \inf \{t \geqq 0 \mid rd(t) - d'(t) - a/b \leqq 0\}$.

The following lemma is an immediate consequence of our assumptions.

<u>Lemma 1</u>: <u>For any</u> a,b <u>and</u> $r > 0$,

$\Psi(t;a,b)$ <u>takes maximum at</u> $T(a/b)$ <u>where</u> $0 < T(a/b) < \infty$, <u>and</u>

$\Psi(t;a,b) > 0$ <u>for all</u> $t \geqq T(a/b)$.

<u>Proof</u>: From our assumption A-1 and the fact $r > 0$, it is straightforward that Ψ is quasi-concave in t. Thus $T(a/b)$ is unique. The fact that $T(a/b)$ is strictly positive and finite is readily proved. By A-2, $\lim_{t\to\infty} \Psi(t;a,b)e^{rt} = \lim_{t\to\infty} [a/r - bd(t)] > 0$, and the last assertion holds. <u>Q.E.D.</u>

Define M(t) to be the payoff to a firm who introduces the product at t, and monopolizes the market thereafter if it is successful. Similarly, let C(t) be the payoff to a firm who introduces at t, knowing the market will be competitive thereafter if it is successful. Finally, let D(t) be the payoff to a duplicator when it duplicates rival's successful product at t.

Formally:

$$(1) \begin{cases} M(t) := \Psi(t;p\pi_M,\beta) = [(p\pi_M/r) - \beta d(t)]e^{-rt}, \\ C(t) := \Psi(t;p\pi_C,\beta) = [(p\pi_C/r) - \beta d(t)]e^{-rt}, \text{ and} \\ D(t) := \Psi(t;\pi_C,1) = \int_t^\infty \pi_C e^{-r\tau}d\tau - d(t)e^{-rt} = [(\pi_C/r) - d(t)]e^{-rt}, \end{cases}$$

where r (>0) is the discount rate common to both firms.

Using these functions the follower's payoff conditional on the leader's success at time t can be defined as follows. If the follower is of type D, it can never duplicates and hence $F(t) = 0$ for all t.

If it is of type D or G, the follower can choose to duplicate or not to duplicate. If it chooses not to duplicate, $F(t) = 0$ for all t again holds.

If it chooses to duplicate and introduces the substitute at time t, it will obtain D(t). In view of the lemma above, if the rival firm introduces the product first and the product turns out successful, a firm always finds duplicating the original product more profitable. Moreover its payoff as the follower is maximized at $T_D := T(\pi_C)$. Thus, its best response as the follower against the rival's successful product innovation at time t, i.e., its optimal time of duplication $t_D(t)$, will satisfy:

$$(2)\quad t_D(t) = \begin{cases} T_D & \text{if} \quad t < T_D \\ t & \text{if} \quad t \geq T_D. \end{cases}$$

As the probability of rival's introduction turns out successful is p,

$$F(t) := D(t_D(t)) = \begin{cases} D^* & \text{if } t < T_D \\ D(t) & \text{if } t \geq T_D \end{cases}$$

where $D^* := D(T_D) = \max_t D(t)$.

Next consider the case a firm introduces the product first (becomes a leader) at time t. If it is of type D, the firm cannot become a leader and L(t) = 0 for all t. If it is of type S or G, L(t) can be positive. If its rival is of type D or G the firm knows that the rival always follows according to the reaction function (2), if its product turns out successful. With probability p it will obtain the profit π_M during the interval $[t, t_D(t))$ and the profit will be reduced to π_C after $t_D(t)$. With probability 1-p, it will obtain nothing. Thus its expected payoff with introduction date t is:

$$L(t) := p[\int_t^{t_D(t)} \pi_M e^{-r\tau} d\tau + \int_{t_D(t)}^{\infty} \pi_C e^{-r\tau} d\tau] - \beta d(t) e^{-rt}$$

$$= \begin{cases} M(t) - (p/r)(\pi_M - \pi_C)e^{-rT_D} & \text{if } t < T_D, \\ C(t) & \text{if } t \geq T_D. \end{cases}$$

Define

$T_M := \inf \{t \mid rd(t) - d'(t) - (p\pi_M/\beta) \leq 0\} = T(p\pi_M/\beta)$, and

$T_C := \inf \{t \mid rd(t) - d'(t) - (p\pi_C/\beta) \leq 0\} = T(p\pi_C/\beta)$.

T_M gives the product-introduction date that maximizes the leader's expected payoff if its rival does not follow immediately. T_C is the introduction date that maximizes the leader's payoff if its rival follows immediately.

If its opponent is of the type S, duplication never takes place and $L(t) = M(t)$ for all t, and the market introduction date is T_M.

If both firms are of type S or G, and jointly introduce the product at time t, each firm expects the joint introduction payoff, $J(t) = C(t)$. This expected payoff to joint introduction reaches the unique maximum at time T_L. If at least one firm is of type D, joint introduction never takes place.

To recapitulate the discussion so far, we list the firm's expected payoff in the game starting at time t conditional on no one having moved or introduced the product before t for all possible cases:

(F): <u>If the rival introduces the product first at</u> t, <u>the expected payoff as the follower is</u>:

(Type S foloower)

$$F(t) = 0 \text{ for all } t.$$

(type D or G follower)

$$F(t) = \begin{cases} D^* & \text{if } t < T_D \\ D(t) = p[(\pi_C/r) - d(t)]e^{-rt} & \text{if } t \geq T_D. \end{cases}$$

(L): <u>If the firm moves as the leader at time</u> t, <u>its expected payoff is</u>:

(Type D leader)

$$L(t) = 0 \text{ for all } t.$$

(Type S or G leader facing to type S follower)

$$L(t) = M(t) \text{ for all } t.$$

(Type S or G leader facing to type D or G follower)

$$L(t) = \begin{cases} M(t) - (p/r)(\pi_M - \pi_C)e^{-rT_D} & \text{if } t < T_D \\ C(t) & \text{if } t \geq T_D \end{cases}$$

(J): <u>If both firms jointly introduce at time</u> t, <u>the expected payoff is</u>

$$J(t) = C(t).$$

Following remarks and lemmas clarify the relationships of these functions.

<u>Remark 1</u>: (i) $M(t) > C(t)$ <u>for all</u> $t > 0$,

(ii) $T_M < T_C$.

The meaning of (i) is straightforward. For M(t) represents the leader's expected payoff under no duplication threat, while C(t) with a threat of immediate duplication. As the higher reward is expected under no duplication threat, the leader's R&D incentive becomes larger and $T_M < T_C$ follows.

<u>Remark 2</u>: (i) $M(t) > D(t)$ <u>for all</u> t <u>if</u> $p \geq \beta$,

(ii) $T_M \{\lesseqgtr\} T_D$ <u>if</u> $p\pi_M/\beta \{\gtreqless\} \pi_C$, <u>namely if</u> $p\pi_M/f(t) \{\gtreqless\} \pi_C/d(t)$.

Note that $\mathrm{sgn}[M(t) - D(t)] = \mathrm{sgn}[(p/r)(\pi_M-\pi_C) + (p-\beta)d(t)]$. (i) holds because $\pi_M > \pi_C$. In other words if duplication advantage (p) is smaller than invention advantage (β), regardless of other factors self-invention gives higher payoff than duplication. (ii) holds because $p\pi_M$ is the advantage of self-invention if not duplicated at all while $\beta\pi_C$ is the duplication advantage.

<u>Remark 3</u>: (i) $C(t) \{\gtreqless\} D(t)$ <u>iff</u> $p \{\gtreqless\} \beta$.

(ii) $T_C \{\lesseqgtr\} T_D$ <u>iff</u> $p \{\gtreqless\} \beta$

(i) follows because $\mathrm{sgn}[C(t) - D(t)] = \mathrm{sgn}[p-\beta]$ and (ii) is immediate.

Recall that $D^* = \max_t D(t) = D(T_D)$. Similarly define:

$$M^* = \max_t M(t) = M(T_M),$$

$$J^* = \max_t J(t) = J(T_J).$$

Proofs for the following three lemmas are relegated to the Appendix.

<u>Lemma 2</u> <u>There exists a function</u> $p = \alpha(\pi_M, \pi_C)$ <u>such that:</u>

$M^* \{\gtreqless\} D^*$ <u>iff</u> $p \{\gtreqless\} \alpha(\pi_M, \pi_C)\beta$,

<u>Furthermore, for any</u> π_M <u>and</u> π_C,

$0 < \alpha(\pi_M, \pi_C) < \pi_C/\pi_M$.

In view of lemma 2, we can divide (β,p)-plane into three regions as shown in Figure 2, each of which gives unique orderings among T_M, T_C and T_D, and among M^*, C^* and D^*.

<u>Region A</u> $(p > \beta)$:	$T_M < T_C < T_D$ and $D^* < C^* < M^*$,
<u>Region B</u> $(\alpha(\cdot,\cdot)\beta < p < \beta)$:	$T_M < T_D < T_C$ and $C^* < D^* < M^*$,
<u>Region C</u> $(\alpha(\cdot,\cdot)\beta < p < (\pi_C/\pi_M)\beta)$:	$T_D < T_M < T_C$ and $C^* < D^* < M^*$,
<u>Region D</u> $(0 < p < \alpha(\cdot,\cdot)\beta)$	$T_D < T_M < T_C$ and $C^* < M^* < D^*$.

The relative shape of the three curves, $D(t)$, $M(t)$ and $J(t)$ is now clear. However, more important is the relative shape of $L(t)$, $F(t)$ and $J(t)$, and especially the relative magnitudes of the maximum values that $L(t)$ and $F(t)$ can take, which we shall denote by L^* and F^*. In particular, if the leader can self-invent and expects follower's duplication, these relative magnitudes are quite complicated. For this, we shall focus on the case GG and classify the parameter space further. Suffix GG to function L, F, etc. will indicate the corresponding functional value in the case GG.

Obviously, $F^*_{GG} = \max_t F_{GG}(t) = F_{GG}(T_D)$ $(= D^*)$. L^*_{GG} is either equal to $L_{GG}(T_M)$ or $L_{GG}(T_C)$. Then;

<u>Lemma 3</u>: <u>There exists a function</u> $p = \nu(\pi_M, \pi_C)$ <u>such that</u>:

$L_{GG}(T_M) \left\{ \substack{> \\ = \\ <} \right\} F^*_{GG}$ <u>iff</u> $p \left\{ \substack{> \\ = \\ <} \right\} \nu(\pi_M, \pi_C)\beta$.

<u>The graph of</u> $p = \nu(\pi_M, \pi_C)\beta$ <u>is contained in the interior of the Region B.</u>

<u>Lemma 4</u>: <u>There exists a function</u> $p = \mu(\pi_M, \pi_C)\beta$ <u>such that:</u>

$L_{GG}(T_M) \left\{ \substack{> \\ = \\ <} \right\} L_{GG}(T_C)$ <u>iff</u> $p \left\{ \substack{> \\ = \\ <} \right\} \mu(\pi_M, \pi_C)\beta$.

<u>The graph of</u> $p = \mu(\pi_M, \pi_C)\beta$ <u>is contained in the interior of the Region B.</u>

Using the results of lemmas 3 and 4, we can further characterize the (β, p)-plane as in Figure 3 and Table 1. Obviously, duplication becomes more advantageous compared to self-invention as one moves into southeastward direction.

Region	T_M, T_C, T_D	M^*, C^*, D^*	L^*_{GG} F^*_{GG}
A	$T_M < T_C < T_D$	$D^* < C^* < M^*$	$L^*_{GG} = L_{GG}(T_M) > F^*_{GG}$
B-1	$T_M < T_D < T_C$	$C^* < D^* < M^*$	
B-2			$L^*_{GG} = L_{GG}(T_M) < F^*_{GG}$
B-3			$L^*_{GG} = L_{GG}(T_C) < F^*_{GG}$
C	$T_D < T_M < T_C$	$C^* < D^* < M^*$	
D		$C^* < M^* < D^*$	

Table 1

The graphs of $L_{GG}(t)$, $F_{GG}(t)$, $J_{GG}(t)$ for three typical cases are illustrated in Figures 4-6. Figure 4 illustrates the case of region A, while region B-1 is practically the same as Figure 4 (except the ordering of T_D and T_C.) Figure 5 illustrates the case of region C, while again the region B-3 is practically identical to this case. Finally, Figure 6 illustrates the case of region B-2.

4. EQUILIBRIA OF CASES G-D AND S-D

In this section, we shall describe (sub-game perfect) equilibrium for the game starting at t=0 for the case G-D or S-D. We begin by defining sub-game perfect equilibrium and equilibrium outcome for general case. Note that the following definition does not allow possibility of joint introduction. (Note that joint introduction is different from immediate duplication.) Providing the precise definition with the possibility of joint introduction is extremely complicated. We advise readers to refer to Fudenberg-Tirole [1984]. Below we provide only heuristic definitions for the case of G-G in order to enhance readers' understanding of structures of our model.

If no firm has introduced the product before $t > 0$, we can speak of a sub-game starting at t. In this sub-game, i's ($i \varepsilon \{1,2\}$) strategy is a function: $G_i^t:[t,\infty) \to [0,1]$. We call G_i^t <u>feasible</u> if it is non-decreasing and right-continuous. G_i^t is the (sub-)probability that firm i will introduce the product at $\tau \geqq t$ conditional on the event that its rival has not done so before τ. Note that we did not impose the condition $\lim_{\tau\to\infty} G_i^t(\tau) = 1$, hence G is not a true cumulative distribution function. Firms may choose not to introduce the product as the leader at all.

Suppose that rival j is adopting a strategy G_j^t. By adopting a "pure" strategy of introducing the product at s ≧ t if j has not done so by s, firm i will obtain the expected payoff of:

$$V_i^t(s,G_j^t) := \int_t^s F(\nu)dG_j^t(\nu) + [1-G_j^t(s)]L(s).$$

When firms are adopting strategies $\{\sigma^t\} := \{G_j^t\}_{j\varepsilon\{1,2\}}$, the expected payoff to the i-th firm for the sub-game starting at t is:

$$V_i^t(\sigma^t) := \int_t^\infty V_i^t(s,G_j^t)dG_i^t(s).$$

Definition: A Nash equilibrium of a sub-game starting at t is a collection of strategies σ^{t*} such that for all i:

$$V_i^t(\sigma^{t*}) \geq V_i^t(G_i^t,G_j^{t*}) \text{ for all feasible } G_i^t.$$

Definition: A sub-game perfect equilibrium is a collection of strategies $\{\sigma^t\}_{t\varepsilon[0,\infty]}$ such that for all i:

(i) $G_i^t(\nu) = G_i^t(\tau) + [1-G_i^t(\tau)]G_i^\tau(\nu)$ for all t,τ,ν such that $t<\tau<\nu$,

(ii) $\{\sigma^t\}$ is a Nash equilibrium for each sub-game starting at t.

Definition: A sub-game perfect equilibrium outcome is an outcome associated with a sub-game perfect equilibrium.

We now describe the equilibrium for cases G-D and S-D. Since they are identical, we only consider the case S-D. For this case, note that firm 2 can only be the follower and 1 can only be the leader. Moreover, the leader's and the follwer's payoffs, $L_{SD}(t)$ and $F_{DS}(t)$ are identical to $L_{GG}(t)$ and $F_{GG}(t)$.

Proposition 1: Firm 1 always introduces the product first obtaining a positive payoff and firm 2 duplicates and receives positive payoff.

Firm 1 will introduce the product when its payoff is maximized (at T_M in regions A, B-1 or B-2, and at T_C in regions B-3, C or D.) Firm 2 will duplicate when its payoff is maximized (at T_D in regions A, B-1 or B-2, and at T_C in regions B-3, C or D.) To provide an intuitive explanation, take Figure 4 illustrating region A. Firm 1, knowing it must become a leader, finds T_M to be the payoff maximizing time of market introduction. Firm 2, knowing duplication is the only strategy, duplicates at T_D. The resulting payoffs are $L^*_{GG} > 0$ for firm 1 and $F^*_{GG} > 0$ for firm 2.

This result clearly shows that the second mover advantage may nullify the first mover advantage. Without the possibility of duplication, firm 1 that invents and introduces the product first can always obtain monopoly profit of M^* ($< L^*_{GG}$) if there is no rival with self-invention ability. However, firms which developed duplication strategy can obtain positive profit by imitating the product, even if it does not spend any resources on self-invention. By duplication, new technology will diffuse and market concentration will be reduced. However, market introduction may be delayed because of the threat of duplication. Namely, without the threat a monopoly firm will introduce at T_M, but the threat may delay it until T_C.

5. EQUILIBRIUM OF CASE S-S

The previous section has seen the R&D competition between a self-inventor and a duplicator. Often times, however, competition takes place between firms who have an access to the same R&D seed. The role of duplication technology in the competition between two self-inventors is an important question. In this section in order to place a proper perspective to this question, we shall investigate competition between two self-inventors who have no duplication possibility.

In this case, once a firm introduced the product to the market, the other firm could not capture any portion of the market. The leader's, the follower's and the joint introducer's expected payoff can be expressed as;

(L) $L_{SS}(t) := M(t) = [(p\pi_M/r) - \beta d(t)]e^{-rt}$ for all $t \geqq 0$,

(F) $F_{SS}(t) := 0$ for all $t \geqq 0$,

(J) $J_{SS}(t) := J(t) = [(p_C\pi/r) - \beta d(t)]e^{-rt}$ for all $t \geqq 0$.

Recall that T_M and T_C denote the dates that maximize expected payoff for the leader (L) and the joint introducer (J). Since a firm can receive positive profit only by becoming a leader, each firm bids for the leadership. The following proposition is immediate:

<u>Proposition 2</u>: <u>There is a following unique equilibrium outcome.</u>

Let $T_S^* := \inf\{t \mid L_{SS}(t) \geqq 0 = F_{SS}(t)\}$. With probability one-half firm 1 introduces the product at T_S^* and firm 2 does not, and with probability one-half the role of the firms is reversed. The date of market introduction is T_S^* with probability one.

The situation is depicted in Figure 5. As each firm can gain only by becoming a leader, the firms try to introduce the product and preempt immediately before the rival does insofar as positive profit can be expected. As a result, each firm's expected payoff $V_{SS} = 0$ in equilibrium.

Two remarks are in order. First, what coordinates two firms' market introduction at T_S^*, despite the fact that the game under consideration is of non-cooperative nature? The answer lies behind our continuous time setup. One might consider that our setup is a limit of discrete models. In a discrete time model, both firms try to introduce the product in the time interval containing T_S^* with probability p between 0 and unity. If neither firms introduce in this interval, both firms try to introduce in the next interval with probability p, and so on. Thus, the market introduction time is distributed over many intervals (because firms try to avoid loss due to joint introduction) and there is a positive probability that joint introduction takes place in each interval.

If we make the length of intervals shorter, two things start to happen. The timing of market introduction starts to be distributed more tightly around T_S^* and, in the limit, becomes degenerate at T_S^*. Moreover, the probability of joint introduction becomes smaller and, in the limit, becomes zero. For more details, see Fudenberg-Tirole [1982].

Second, our result of symmetric outcome hinges crucially upon the symmetric nature of the game. If a firm has the first-mover advantage and has even a slight advantage in payoff or cost, it preempts the rival completely.

6. EQUILIBRIUM OF CASE G-S

Without loss of generality, we assume that firm 1 has both duplication and self-invention capital (G) while firm 2 has only the latter (S). The expected payoff for each firm can be expressed as follows:

Firm 1's payoff:

(L) $L_{GS}(t) := M(t) = [(p\pi_M/r) - \beta d(t)]e^{-rt}$ for all $t \geqq 0$,

(F) $F_{GS}(t) := D^* = p[(\pi_C/r)-d(T_D)]e^{-rT_D}$ for all $t \in [0,T_D)$

$D(t) = p[(\pi_C/r)-d(t)]e^{-rt}$ for all $t \in [T_D,+\infty)$

(J) $J_{GS}(t) := C(t) = [(p\pi_C/r)-\beta d(t)]e^{-rt}$ for all $t \geqq 0$.

Firm 2's payoff:

(L) $L_{SG}(t) := M(t)-(p/r)(\pi_M-\pi_C)e^{-rT_D}$ for all $t \in [0,T_D)$,

$C(t)$ for all $t \in [T_D,+\infty)$,

(F) $F_{SG}(t) := 0$ for all $t \geqq 0$,

(J) $J_{SG}(t) := C(t)$ for all $t \geqq 0$,

where $L_{GS}(t)$ represents the expected payoff for type G firm when it becomes a leader. $L_{SG}(t)$, $F_{GS}(t)$ and the rest are similarly defined.

In the present case, the only equilibrium involves preemption by firm 1 having duplication capital. Formally:

<u>Proposition 3</u>: <u>There is a unique equilibrium that firm 1 preempts firm 2 at date</u> $T^{**} := \inf\{t \mid L_{SG}(t) \geqq F_{SG}(t) = 0\}$. <u>Firm 1 obtains the expected payoff</u> $V_{GS} = L_{GS}(T^{**}) > F_{GS}(T^{**})$ <u>and firm 2 the payoff</u> $V_{SG} = 0$.

<u>Proof</u>: As firm 2's payoff is positive only when it becomes a leader, it is willing to expedite market introduction date up to T^{**} when the payoff by becoming a leader vanishes. For firm 1, there are two alternatives: to preempt the firm 2 at T^{**} or to wait for 2's introduction, say, at t. If 1 preempts 2, 1's payoff is $L_{GS}(T^{**})$. If 1 waits for 2's introduction at t, 1 will receive $F_{GS}(t)$. In order to analyze relative magnitude of these two payoffs, consider the following two cases:

<u>Case 1</u>: If $T^{**} \leqq T_D$, $F_{GS}(T_D) = \max_t F_{GS}(t) = F_{GS}(t)$ for all $t \leqq T_D$. Then;

$$L_{GS}(T^{**}) - F_{GS}(t_D(t)) \geqq L_{GS}(T^{**}) - F_{GS}(T_D) = L_{GS}(T^{**}) - F_{GS}(T^{**}).$$

<u>Case 2</u>: If $T^{**} > T_D$, $t \geqq T^{**} > T_D$ as 2 never introduces before T_D. Then:

$$L_{GS}(T^{**}) - F_{GS}(t_D(t)) = L_{GS}(T^{**}) - F_{GS}(t).$$

Since $F'_{GS}(t) < 0$ for all $t > T_D$, it follows that

$$L_{GS}(T^{**}) - F_{GS}(t) > L_{GS}(T^{**}) - F_{GS}(T^{**}).$$

Thus, it suffices to prove $\gamma(t) := [L_{GS}(t) - F_{GS}(t)] - L_{GS}(t) > 0$ holds for all $t \geqq 0$. However, for all $t \leqq T_D$,

$$\gamma(t) = \{(p\pi_M/r) - \beta d(t)\}e^{-rt} - p\{(\pi_C/r) - d(T_D)\}e^{-rT_D}$$
$$- [(p\pi_M/r) - \beta d(t)\}e^{-rt} - (p/r)(\pi_M - \pi_C)e^{-rT_D}]$$

$$= (p/r)[(\pi_M - 2\pi_C) + rd(T_D)]e^{-rT_D} > 0,$$

where the last inequality follows from A-4. On the other hand, for all $t > T_D$,

$$\gamma(t) = (p/r)[(\pi_M - 2\pi_C) + rd(t)]e^{-rt} > 0,$$

by A-4. This proves the proposition. Q.E.D.

Thus, developing duplication capital provides a strategic advantage even if both firms have the ability to self-invent. By doing so, the firm can preempt its rival and secure the market for itself. Note however, if a firm has duplication strategy the market introduction date is delayed compared to the case of S-S. This is so because $L_{SG}(t) < L_{SS}(t)$ holds for any t and $T^{**} > T^{*}$ follows.

Faced with the possibility of being preempted, the rival which has not developed duplication capital has an incentive to do so. In the next section, we shall consider the case where both firms have both duplication and self-invention possibilities.

7. EQUILIBRIUM OF THE CASE G-G

There are three different types of equilibria.

Proposition 4: *If $L^*_{GG} = L_{GG}(T_M) > F^*_{GG}$, i.e., (β, p) lies in the Region A or B-1, there is a following unique distribution of equilibrium outcomes.*

Let $T^*_G := \inf\{t | L_{GG}(t) \geq F_{GG}(t)\}$. With probability one-half firm 1 introduces the product at T^*_G and firm 2 duplicates it at T_D, with probability one-half the role of the firms are reversed. Thus with probability one, the dates of introduction and duplication are T^*_G and T_D. In this equilibrium each firm receives the same expected payoff $V_{GG} = F^*_{GG}$.

Proposition 5: If $L_{GG}(T_C) < L^*_{GG} = L_{GG}(T_M) < F^*_{GG}$, i.e., (β,p) lies in the Region B-2, there are two types of equilibria; asymmetric and symmetric.

In the asymmetric equilibrium, firm 1 (or 2) introduces the product at T_M receiving the payoff $L_{GG}(T_M)$, while firm 2(or 1) duplicates it at T_D receiving the payoff $F_{GG} = F_{GG}(T_D)$.

In the symmetric equilibrium, each firm adopts the identical mixed strategy G(t) such that:

$$G(t) = \begin{cases} 0 & \text{for all } t\varepsilon[0,T_M), \\ 1 - \exp(-\int_{T_M}^{t} H(s)ds) & \text{for all } t\varepsilon[T_M,T_D), \\ 1 - \exp(-\int_{T_M}^{T_D} H(s)ds) & \text{for all } t\varepsilon[T_D,T_C), \\ [1 - \exp(-\int_{T_M}^{T_D} H(s)ds)] + \exp(-\int_{T_M}^{T_D} H(s)ds)[1 - \exp(-\int_{T_C}^{t} H(s)ds)] & \text{for all } t\varepsilon[T_C,+\infty). \end{cases}$$

where $H(t) := \dfrac{-L'_{GG}(t)}{F_{GG}(t)-L_{GG}(t)}$. In this equilibrium each receives $V_{GG} = L_{GG}(T_M)$.

Proposition 6: If $L^*_{GG} = L_{GG}(T_C) < F^*_{GG}$, i.e., (β,p) lies in the Regions B-3, C or D, there are two types of equilibria again; asymmetric and symmetric.

In the asymmetric equilibrium, firm 1 (or 2) introduces the product at T_C with the expected payoff $L_{GG}(T_C)$ and firm 2 (or 1) immediately duplicates it with the expected payoff $F_{GG}(T_C)$.

In the symmetric equilibrium, each firm adopts the identical mixed strategy G(t) such that

$$G(t) = \begin{cases} 0 & \text{for all } t \varepsilon [0, T_C) \\ 1 - \exp(-\int_{T_C}^{t} H(s)ds) & \text{for all } t \varepsilon [T_C, +\infty). \end{cases}$$

In this symmetric equilibrium each will obtain $V_{GG} = L_{GG}(T_C)$.

We shall provide intuitive explanations why these Propositions obtain. Take Proposition 4 first, depicted in Figure 4. Since $L^*_{GG} = L_{GG}(T_M) > F^*_{GG}$, the $L_{GG}(t)$ schedule is located above the $F_{GG}(t)$ schedule over some region. Insofar as a firm can obtain a payoff larger than F^*_{GG}, it will try to introduce the product earlier and preempt the rival. As both firms have this incentive, the product is introduced at T^*_G when the benefits of becoming a leader disappears. Note, however, that they will flip a fair coin (in the sense explained in section 5) in deciding who will become a leader at time T^*_G in order to avoid the loss due to joint introduction. That each firm will obtain the identical expected payoff $V_{GG} = L_{GG}(T^*_G) = F^*_{GG}$ follows from the definition of T^*_G.

Next consider Proposition 6 (see Figure 6) which is simpler than Proposition 2. Since $F^*_{GG} > L^*_{GG} = L_{GG}(T_C)$ holds, each firm finds duplication more profitable than becoming a leader at any time $t \geqq 0$.

The asymmetric equilibrium is as follows. If a firm decides to become a leader, it will introduce the product at the time that maximizes the leader's payoff, T_C. The rival, by taking the strategy of not becoming a leader regardless of the situation, can force the firm to become a leader. Thus, a leader must introduce at T_C immediately followed by its rival. The resulting payoff structure is obvious.

On the other hand, both firms may choose mixed strategy for the product introduction. Each firm knows, however, that even in the worst case of becoming a leader, the gain of $L_{GG}(T_C)$ is assured. Thus neither firm will choose a move to become a leader before T_C.

Let the symmetric mixed strategy be denoted by G(t), the cumulative probability that the firm moves as a leader at time t if no firm has introduced the product yet. Given that the rival uses this mixed strategy, a firm, by moving as a leader at time $t(\geq T_C)$, expects to obtain;

$$V(t;G) = \int_0^t F_{GG}(s)dG(s) + [1-G(t)]L_{GG}(t),$$

At equilibrium the payoff V(t;G) should be equal on the support of $G'(\cdot)$, for otherwise firms will have an incentive to change the strategy. Thus:

$$\partial V(t;G)/\partial t = G'(t)[F_{GG}(t)-L_{GG}(t)] + [1-G(t)]L_{GG}'(t) = 0, \quad \text{or}$$

$$G'(t) = [1-G(t)]H(t) \quad \text{for all } t \text{ with } G(t) \geq 0.$$

Solving this differential equation for G(t), we obtain:

$$G(t) = 1 - \exp(-\int_{T_C}^t H(s)ds) \text{ for } t \geq T_L,$$

which gives the result in Proposition 6. Substituting this distribution function $G(\cdot)$ into V(t;G) and evaluating it at $t=T_C$, we obtain

$$V(t;G) = V(T_C;G) = L_{GG}(T_C) \text{ for all } t \geq 0.$$

That is, each firm's equilibrium payoff V_{GG} is equal to $L_{GG}(T_C)$.

Finally consider Proposition 5 (see Figure 7) where $L_{GG}(T_C) < L^*_{GG} = L_{GG}(T_M) < F^*_{GG}$. In this case too, duplication profit is always larger than self-invention. Arguments for the asymmetric equilibrium are identical to those for Proposition 5 and we focus on the symmetric equilibrium.

As in the previous case, a firm can ensure itself at least $L^*_{GG} = L_{GG}(T_M)$ and has no incentive to move before T_M. After T_D it becomes advantageous to wait till T_C, because the payoff to introduce (as a leader) at T_C is strictly higher than $L_{GG}(t)$ for any $t \in [T_D, T_C)$. So it will move only during $[T_M, T_D)$ and $[T_C, +\infty)$. Using the payoff equalization property of the mixed strategy equilibrium, assertion of Proposition 6 follows.

Three remarks are in order. First, in Propositions 5 and 6 we obtained two different types of equilibria. Which type of equilibria is more likely to obtain? To solve multiplicity of Nash equilibria, two criteria have been proposed to distinguish the most likely outcome (see, for example, Fudenberg-Tirole [1984].) One is to choose the equilibrium that gives rise to the most efficient outcome. This would lead to our asymmetric equilibrium. The other is to choose a focal point equilibrium as suggested by Schelling [1960]. This would lead to our symmetric equilibrium as symmetricity is an obvious candidate for a focal point.

Despite the fact that there is no satisfactory theory in general, we strongly feel the symmetric equilibrium should emerge as equilibrium in our setup. In the asymmetric equilibrium, a firm can obtain a larger payoff compared to the rival's not because it actively seeks for the benefit but because the rival is, by stupidly or neglect, allowing the extra benefit. Based on this observation, we shall assume the symmetric equilibrium to be the outcome whenever there are multiple equilibria.

The second remark is concerned with the timing of product introduction. Take the case of Proposition 6 and assume the symmetric equilibrium obtains. Then the date of product introduction might be postponed far into the future. To see how serious this problem of R&D delay is, calculate the social expected time of the product introduction $\hat{T}$. It is given by:

$$\hat{T} := 2\int_{T_C}^{\infty} tH(t)\exp(-2\int_{T_C}^{t} H(s)ds)dt = T_C + \int_{T_C}^{\infty} \exp(-2\int_{T_C}^{t} H(s)ds)dt.$$

It can easily be shown that $\hat{T}$ depends negatively upon p/β and π_C. An increase in p/β implies that self-invention is comparatively more advantageous than duplication. This makes the market introduction date $\hat{T}$ earlier. On the other hand, a rise in π_C reduces the leader's loss forced by the follower's duplication. It increases the relative advantage of becoming a leader and augments the probability that a firm will introduce the product earlier.

The last remark is concerned with the possibility of joint introduction. Despite the similarity of the current setup and that of Fudenberg-Tirole [1984], no joint introduction arises in equilibrium of the present model. Joint introduction arises only if coordination of the timing of product introduction is advantageous compared to preempting the rival. In Fudenberg-Tirole, there is such an advantage as postponing the introduction will secure profits that would be lost once the new product were introduced. It is our assumption of no such profit that eliminates joint introduction as an equilibrium outcome. An explicit consideration of such profit, however, will never hurt the core of our analysis.

8. ECONOMIC IMPLICATION OF DUPLICATION STRATEGY

In the previous sections, we have touched upon meaning of duplication strategies in each case where firms commit to self-invention/duplication capitals. In this section we shall first analyze the incentive to invest in these capitals. Then, we shall evaluate implications of duplication strategies in a broader perspective.

In order to analyze the incentive to invest in self-invention and/or duplication capital, assume first that the commitment costs C_S and C_D are both zero. Then, depending upon which strategy each firm chooses from {S,D,G}, the resulting payoff is as shown in the payoff matrix in Table 2.

If the choice of capital {S,D,G} is made simultaneously, the equilibrium of the entire game is nothing but the Nash equilibrium of this matrix. Using the definition of T^{**}, it is easily seen that $L_{GS}(T^{**}) > F^*_{GG}$. Moreover Propositions 4-6 implies that $V_{GG} \leqq F^*_{GG}$. The equality holds, however, when (p, β) lies in Regions A or B-1. Therefore when the parameter pair (p, β) lies in either Region A or Region B-1, committing to the general technology G is a dominant strategy for each firm. Resulting game is characterized by Tthe game of waiting as asserted in the previous section. When the parameter pair (p, β) lies in the other regions, however, pairs G-D and D-G become a Nash equilibrium. The firm having committed to the general technology will become the leader because the rival cannot introduce the product by itself.

1 \ 2	S	D	G
S	0, 0	$L_{GS}(T^{**})$, F^{*}_{GG}	0, $L_{GS}(T^{**})$
D	F^{*}_{GG}, L^{*}_{GG}	0, 0	F^{*}_{GG}, L^{*}_{GG}
G	$L_{GS}(T^{**})$, 0	L^{*}_{GG}, F^{*}_{GG}	V_{GG}, V_{GG}

Table 2

Suppose, next, that the firm 1 is the incumbent and can choose the capital from {S,D,G} before firm 2 (the entrant) can choose, as is usually assumed in the entry-detrrence literature. First consider the case in which (p, β) lies in either Region A or Region B-1. In these regions, the probability of R&D success is sufficiently high compared to the easiness of duplication. Here $V_{GG} = F^{*}_{GG} < L^{*}_{GG}$ holds as Table 1 and Proposition 4 suggest. Furthermore we note that $L^{*}_{GG} > L_{GS}(T^{**})$ holds too. In this case, firm 1, by committing to the general technology can induce firm 2 to choose the duplication strategy, thus obtaining L^{*}_{GG} as the leader. (To be more precise, firm 2 is indifferent between two strategies D and G, and may use a randomized strategy. However insofar as its probability of choosing strategy D is positive, firm 1's expected profit becomes higher than V_{GG}.)

On the other hand, if (p, ß) lies in the other regions, i.e., duplication is sufficiently inexpensive compared to the probability of success, becoming the follower is likely to be more profitable than becoming the leader, as $V_{GG} < F^*_{GG}$ holds. In this case, firm 1, by committing to duplication strategy, can induce firm 2 to either take self-invention strategy S or general-technology strategy G. In either case, firm 1 succeeds in forcing the rival to become the leader and earning a share of the rival's successful R&D fruit without taking any R&D risk.

In the second scenario of incumbent-entrant game, we have ignored the commitment costs for each strategy. however, the above analysis is robust insofar as the two commitment costs, C_S and C_D, are sufficiently small. Moreover, the above analyses suggest that the strategy pair S-S will never arise unless C_S is significantly smaller than C_D, the case where the payoff net of commitment cost is zero. Thus whatever state results, our analysis shows that the often neglected duplication possibility is normally adopted as an equilibrium strategy to obtain the second-mover advantage.

To evaluate welfare effects of duplication possibility, two aspects are worth investigating; diffusion possibility and market introduction timing. If invention diffuses and more firms introduce the products (or its substitutes), product market will become more competitive and presumably economic welfare will be augmented. On the other hand, to evaluate welfare implication of invention timing non-appropriability of invention benefit plasys an important role. Counting the benefit accruable to consumers, the welfare optimizing invention must occur when the discounted sum of the economic welfare (the sum of inventor's profit and consumers' surplus) is maximized. We must evaluate the implication of duplication possibility both from this welfare viewpoint as well as strategic viewpoint.

We shall first consider when, without duplication possibility, one firm is known to capture the market. Therefore, the monopolist, who knows it can obtain M(t) depending when it introduces the product, chooses T_M to be the timing of market introduction and obtains M^*. T_M is likely to be later than the welfare maximizing invention timing. For part of the invention benefit will be spilled over to consumers.

Consider next the case in which a rival firm has duplication possibility. Since duplication possibility makes the duplicator introduce the substitute, clearly it benefits the society in that diffusion starts to occur. Consumers are likely to benefit by the lower price of the new product. Moreover, market introduction timing remains the same unless duplication is relatively inexpensive and it takes place immediately after self-inventor's introduction. In this case, market introduction would be delayed till T_C compared to the monopolist' timing T_M .

However, duplication may deprive of the possibility of self-invention (and hence introduction of the product) altogether. Suppose there is an incembent firm that has already comitted to duplication capital but not to self-invention capital. Knowing this, entrant must evaluating the benefit of spending resources (of the amount C_S) on self-invention-capital. Assume moreover:

$$M^* > C_S > L^*_{SD}.$$

This is possibile because M^*, being the maximum possible payoff a firm can obtain by introducing the product, is always larger than L^*_{SD}.

Had the incumbent not committed to the duplication possibility, entrant must have invested in self-invention capital as $M^{*}>C_{S}$. However, in the assumed situation, this incentive would disappear and the product would never be introduced as the maximum payoff L^{*}_{SD} is less than the cost to develop self-invention capital. It should be stressed that the product is socially worth introduced because, even if we do not count consumer's surplus, net benefit $M^{*}-C_{S}$ is positive.

If there are more than one firms which have already invested in self-invention capital, similar implications are obtained. As is shown in section 5, without duplication possibility preemption must always occur in the case of S-S. Invention does not diffuse but introduction timing is earlier (possibly too early from the social welfare viewpoint.) In such a situation, firms have an incentive to develop duplication capital. For, by doing this, the firm which has developed duplication capital can assure itself positive profit, $L_{GS}(T^{**}) > 0$. Market introduction timing becomes later, but diffusion starts to occur.

Moreover, faced with a rival with both self-invention and duplication capital, a firm without duplication possibility is sure to be preempted. As long as duplication benefit, F^{*}_{SG}, is no smaller than the cost for duplication capital, C_{D}, the firm has incentive to invest in duplication capital.

To sum, contrary to the anticipation by the ε-preemption or persistence of monopoly argument, duplication strategy is a strategy which benefits many firms and it often enhances the social welfare by promoting diffusion of new technology.

9. CONCLUDING REMARKS

In this paper, we analyzed a game where two firms compete each other on the timing of a product introduction to market. We assume that, by committing resources to duplication technology, a firm can prevent itself from being preempted. This kind of strategy seems to be prevalent in industries where research and development is a major determinant of a firm's performance. In particular, large established firms seems to employ this strategy so that they can copy any successful new products introduced by rivals and/or entrants.

Our result that a firm employing this strategy may preempt rivals sheds some light on why such strategies are prevalent. We think that our result is much stronger than it suggests literally. In our model, there is only one product possibility and hence investing on duplication strategy sometimes reveals to be unprofitable. However, if there are more than one potential new products and if the duplication technology gives an opportunity to imitate all such products, this strategy should become unquestionably more profitable. By investing on general knowledge for duplication, a firm can reduce the R&D risk which it must bear and furthermore allows it to tailor the leader's successful R&D result better suited for the market demand condition and capture a significant portion of the new market.

The persistence of monopoly debate, discussed briefly in the introduction, is undeniably motivated by the persuasive arguments given by Schumpeter that innovative destructions are the driving force of the market systems. In his view, it is a newcomer to market who provides such an innovative destruction. If it is always the current monopolist who provides innovation, the world of Schumpeter would never appear, which is what the persistence of monopoly argument by Gilbert and Newberry [1982] argued.

However our argument revives Schumpeterian world in a little bit different way than Reinganum [1983] discussed.

She argued that when the R&D result is "drastic" in the sense that it makes all the existing technology obsolete and when the success of R&D is sufficiently uncertain, the the firm with the first-mover advantage may not have greater R&D incentive than second-movers. Her result hinges upon the absence of duplication strategy discussed in the present paper.

However, by taking duplication possibility into account, we showed that the first-mover firm may not be able to preempt the second-movers who have committed to duplication strategy, and that the monopoly will not persist. The duplication strategy yields the second-mover advantage in mitigating the R&D risk that the leader is forced to bear.

One of the important insights drawn from this result is as follows. Without investing in duplication technology a firm will be easily preempted by its rival, for once the rival succeeds in R&D the firm's profit is forced to zero. For this reason, firms are motivated to develop duplication strategy as a measure to fight against rival's preemption.

Furthermore when the R&D risk is large relative to the easiness of duplication technology (i.e., p is small relative to β), a firm with the first-mover advantage may commit only to the duplication strategy and concede the leader's position to a newcomer so as to avoid the R&D risk. The incumbent with the first-mover advantage tends to sit and wait for the results of risky R&D experiments by venturous newcomers. Risky R&D activities are first initiated by small newcomers, while large incumbents tend to take the "lean-and-hungry-look" strategy for such risky projects.

From the viewpoint of economic welfare, as argued in section 7 if both firms happen to commit to self-invention and duplication capitals, the resulting game will become that of waiting and the product may be introduced later than the time that maximizes the social welfare. However, except such a case, duplication possibility generally prevents the excessive R&D incentive of the leader and additionally yields social gains from diffusion: the market will become more competitive and the social welfare will be enhanced.

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APPENDIX

In this Appendix, we give the proofs of Lemmas 2, 3 and 4 in the text. We begin by providing the following additional lemma.

Lemma A: If $p = (\pi_C/\pi_M)$, then $M^* > D^*$.

Proof: Note first that, under the given condition, $T_M = T_D$ holds dues to Remark 2 in the text. From the definition of M^* and D^*, we have:

$M^* = -(\beta/r0d'(T_D)e^{-rT_D}$ and

$D^* = -(p/r)d'(T_D)e^{-rT_D}$.

Taking the ratio, we obtain:

$M^*/D^* = \beta/p = \pi_M/\pi_C > 1.$ Q.E.D.

Proof of Lemma 2 Given π_M and π_C, define $\omega(p, \beta) := M^* - D^*$, where $M^* := [(p\pi_M/r) - \beta d(T_M)]e^{-rT_M}$, $D^* *= p[(\pi_C/r) - d(T_D)]e^{-rT_D}$, $T_M := T(p\pi_M/\beta)$, and $T_D := T(\pi_C)$. We first note that $\omega(p, \beta)$ is linear-homogenous in p and β, for T_M and T_D are invariant for proportional changes in p and β, and M(t) and D(t) are linear-homogenous in p and β. This implies that $\omega(p, \beta) = \beta\omega(p/\beta, 1)$ and sgn $\omega(p, \beta)$ depends only on p/β.

Denote by $\alpha(\pi_M, \pi_C)$ the critical value of p/β that satisfies $\omega(\alpha(\pi_M, \pi_C), 1) = 0$ and $\alpha(\pi_M, \pi_C) > 0$. We first prove that such a positive critical value exists.

For this purpose, differentiate $\omega(p, \beta)$ and obtain:

$\omega_p(p, \beta) = (\pi_M/r)e^{-rT_M} - [(\pi_C/r) - d(T_D)]e^{-rT_D}$,

where use was made of the envelope theorem. We note that the second bracketed term is a positive constant insofar as π_C is a positive constant. However as $T_M = T(p\pi_M/\beta)$ and T(a) is strictly monotone-decreasing satisfying

$\lim_{a \to +0} T(a) = +\infty\pi$, the first term approaches to zero as p approaches to zero. Therefore since $\omega(0, \beta) = 0$, for sufficiently small p $\omega_p(p, \beta) < 0$ and thus $\omega(p, \beta) < 0$ follows. However, as $\omega(p, \beta) > 0$ for $p = (\pi_C/\pi_M)\beta$ from Lemma A and $\omega(p, \beta)$ is continuous in p and β, by the intermediate value theorem there must exist a value $\alpha \in (0, \pi_C/\pi_M)$ such that if $p = \alpha\beta$ then $\omega(p, \beta) = 0$. Noting that monotone-increasing property of T_M in p implies that of $\omega(p, \beta)$ in p, such an value α must be unique, and this α is $\alpha(\pi_M, \pi_C)$ stated above. Q.E.D.

Proof of Lemma 3 Given π_M and π_C, let $A(p, \beta) := L_{CC}(T_M) - F^*_{CC}$. As in the proof of Lemma 2, it is straightforward to see that $A(p, \beta)$ is linear-homogeneous in p and β. Now there are two possible cases to occur.

Case 1: $T_D \leqq T_M$

In this case a pair (p, β) must lie in Regions C or D. So the leader is always caught up with immediately by the follower, and $\arg\max_t L_{CC}(t) = T_C$. This implies that $L_{CC}(T_M) < L_{CC}(T_C) = C^*$. Noting this fact, we obtain:

$$A(p, \beta) = L_{CC}(T_M) - F^*_{CC} < C^* - D^* < 0,$$

where the last inequality follows from the fact that (p, β) lies in either Region C or Region D. Therefore $A(p, \beta)$ cannot be positive in Regions C and D.

Case 2: $T_M < T_D$

In the present case (p, β) lies in either Region A or Region B. Here

$$A(p, \beta) = M^* - D^* - (p/r)(\pi_M - \pi_C)e^{-rT_D}.$$

As $A(p, \beta)$ is linear-homogeneous in p and β, sgn $A(p, \beta)$ depends only on $p.\beta$. Denote by $\nu(\pi_M, \pi_C)$ the critical value of p/β satisfying $A(\nu(\pi_M, \pi_C)\beta, \beta) = 0$. To prove that such $\nu(\pi_M, \pi_C)$ exists, let us consider $p \geqq \beta$. Then

$$A(p, \beta) > [(p\pi_M/r) - \beta d(T_D)]e^{-rT_D} - p[(\pi_C/r) - d(T_D)]e^{-rT_D}$$

$$- (p/r)(\pi_M - \pi_C)e^{-rT_D}$$

$$= (p - \beta)d(T_D)e^{-rT_D} > 0.$$

As $A(p, \beta)$ is continuous in p and β, and since $A(p, \beta) < 0$ for $p < (\pi_C/\pi_M)\beta$ and $A(p, \beta) > 0$ for $p \geq \beta$, there must exist some $\nu(\pi_M, \pi_C) \in (\pi_C/\pi_M, 1)$ such that $A(\nu(\pi_M, \pi_C)\beta, \beta) = 0$.

Lastly to prove that $\nu(\pi_M, \pi_C)$ is unique, differentiate $A(p, \beta)$ with respect to p and obtain:

$$pA_p(p, \beta) = A(p, \beta) - \beta A_\beta(p, \beta),$$

where use was made of linear-homogeneity of $A(p, \beta)$. As $A_\beta(p, \beta) < 0$ always holds, the above equation implies that $A_p(p, \beta) > 0$ whenever $A(p, \beta) \geq 0$. This established once A becomes positive with a rise in p A never becomes negative with a further rise in p. <u>Q.E.D.</u>

<u>Proof of Lemma 4</u> Given π_M and π_C, define $B(p, \beta) := L_{CC}(T_M) - L_{CC}(T_C)$. As in the proofs of Lemmas 2 and 3, $B(p, \beta)$ is continuous and linear-homogeneous in p and β. Now there are two cases to consider.

<u>Case 1:</u> $T_D \leq T_M$

In this case the leader is always caught up with immediately by the follower, and thus $\max_t L_{CC}(t) = L_{CC}(T_C)$. So $B(p, \beta) < 0$. This implies that insofar as (p, β) is in Regions C and D, $B(p, \beta) < 0$. (Note that on the boundary of Region C it is easy to ascertain in a similar fashion that $B(p, \beta) < 0$.

<u>Case 2:</u> $T_M < T_D$

In this case (p, β) is in either Region A or Region B. We first establish that there exists some $\mu(\pi_M, \pi_C) \in (\pi_C/\pi_M, \nu(\pi_M, \pi_C))$ such that for any β $B(\mu(\pi_M, \pi_C)\beta, \beta) = 0$. For this purpose, it suffices to prove that $\mu(\pi_M, \pi_C) < \nu(\pi_M, \pi_C)$. Consider $p = \nu(\pi_M, \pi_C)\beta$. Then by Lemma 3,

$$\begin{aligned} B(p, \beta) &= L_{CC}(T_M) - L_{CC}(T_C) \\ &= F^*_{CC} - L_{CC}(T_C) \\ &> p[(\pi_C/r) - d(T_C)]e^{-rT_C} - [(p\pi_C/r) - \beta d(T_C)]e^{-rT_C} \\ &= (\beta - p)d(T_C)e^{-rT_C} > 0, \end{aligned}$$

where use was made of $p = \nu(\pi_M, \pi_C)\beta < \beta$. As $B(p, \beta) < 0$ for all $p \leq (\pi_C/\pi_M)\beta$ and $B(p, \beta)$ is continuous in p and β, there exists some $\mu(\pi_M, \pi_C) \in (\pi_C/\pi_M, \nu(\pi_M, \pi_C))$ such that $B(\mu(\pi_M, \pi_C)\beta, \beta) = 0$.

Lastly to prove that $\mu(\pi_M, \pi_C)$ is unique, differentiate $B(p, \beta)$ with respect to p and β, and obtain:

$$pB_p(p, \beta) = B - \beta B_\beta(p, \beta),$$

$$B_\beta(p, \beta) = d(T_C)e^{-rT_C} - d(T_M)e^{-rT_M},$$

where use was made of the envelope theorem. As $T_M < T_C$ and $d(t)e^{-rt}$ is monotone-decreasing in t, $B_\beta(p, \beta) < 0$ follows. So insofar as $B \geqq 0$ $B_p(p, \beta) > 0$ holds. Thus once B becomes positive with a rise in p, it never becomes negative again with a further rise in p. This establishes that $\mu(\pi_M, \pi_C)$ is unique. Q.E.D.

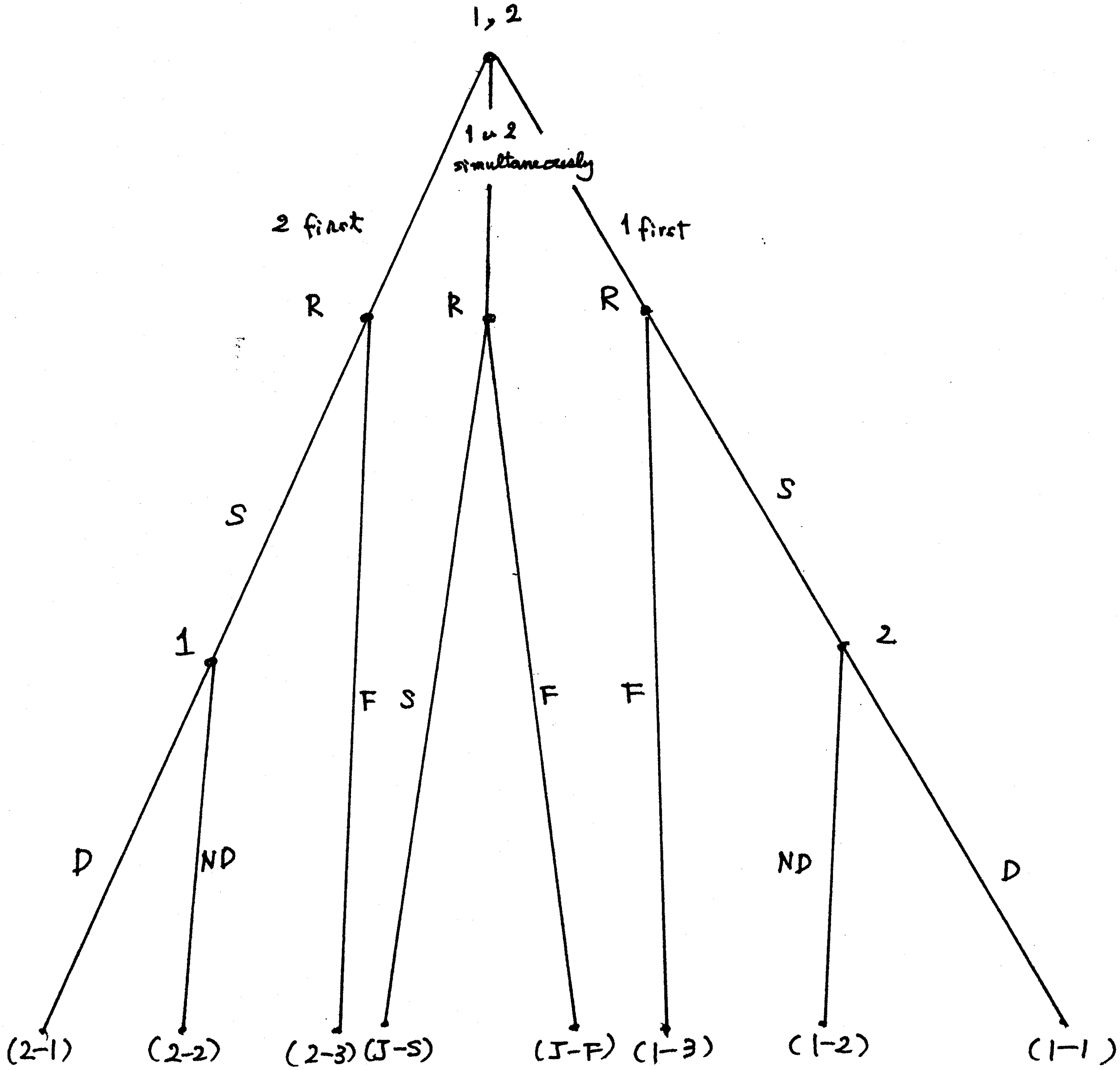

1, 2
1 & 2 simultaneously
2 first
1 first
R
R
R
S
S
1
2
F
S
F
F
D
ND
ND
D
(2-1)
(2-2)
(2-3)
(J-S)
(J-F)
(1-3)
(1-2)
(1-1)

Figure 1

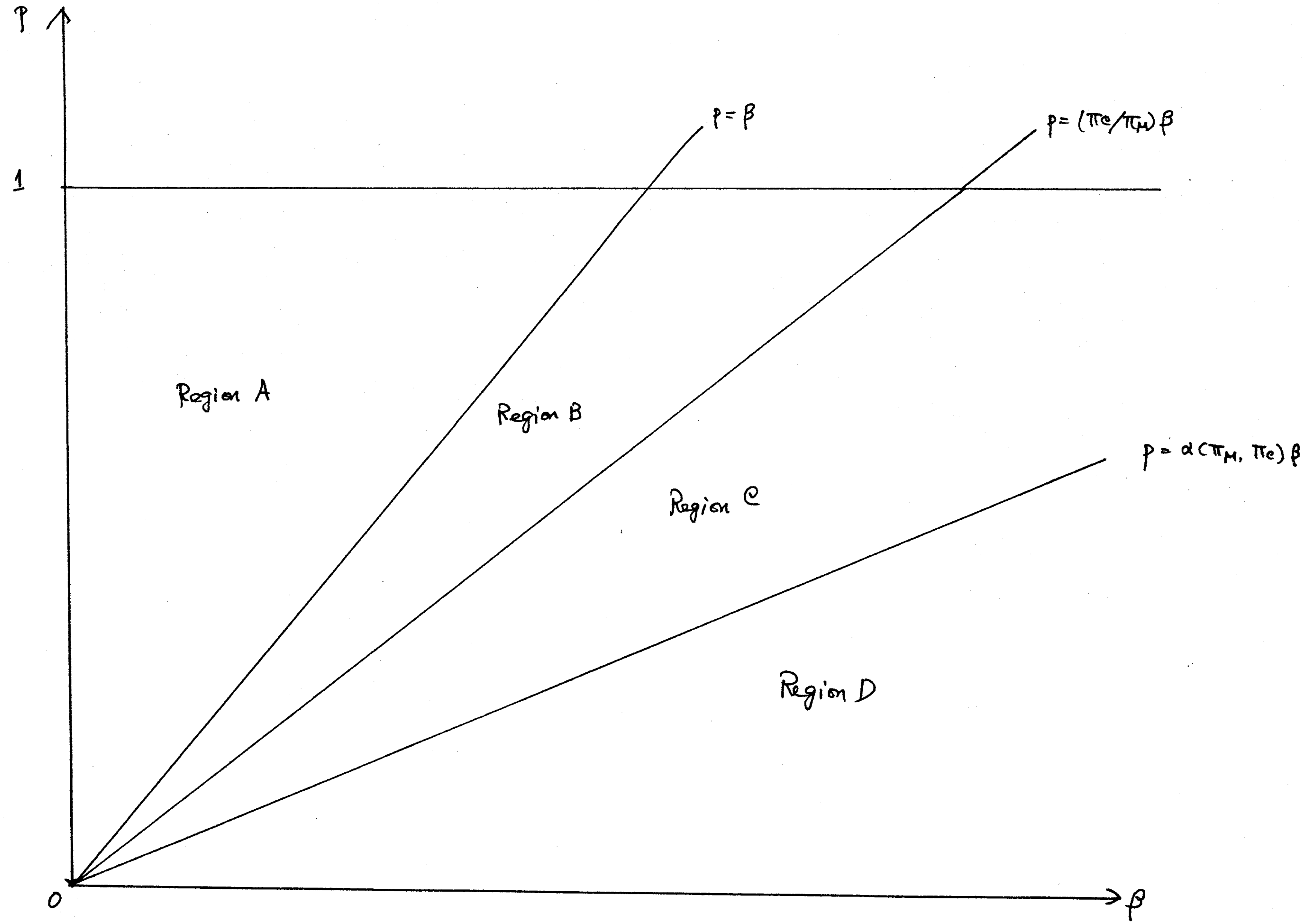


Figure 2

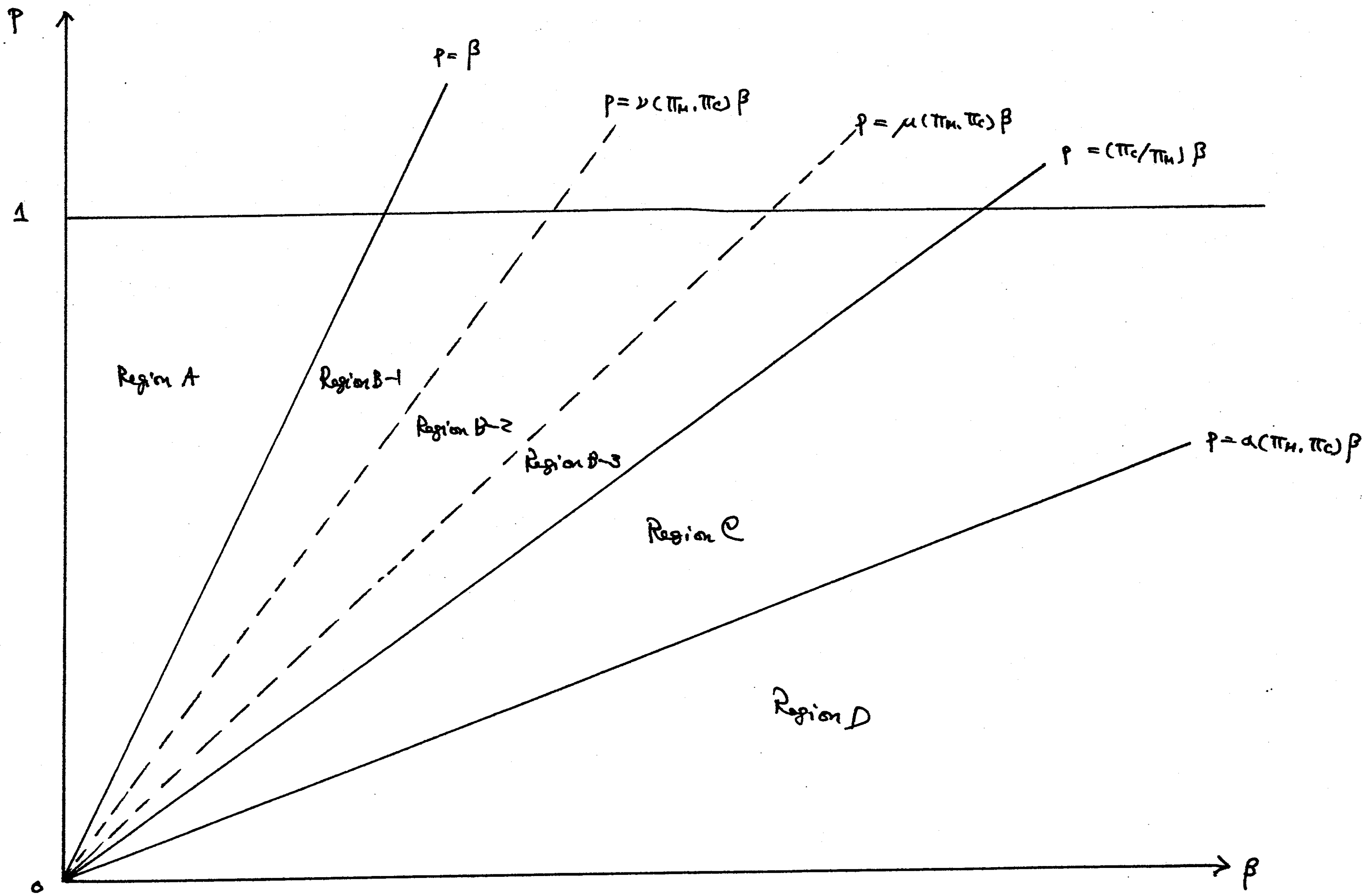
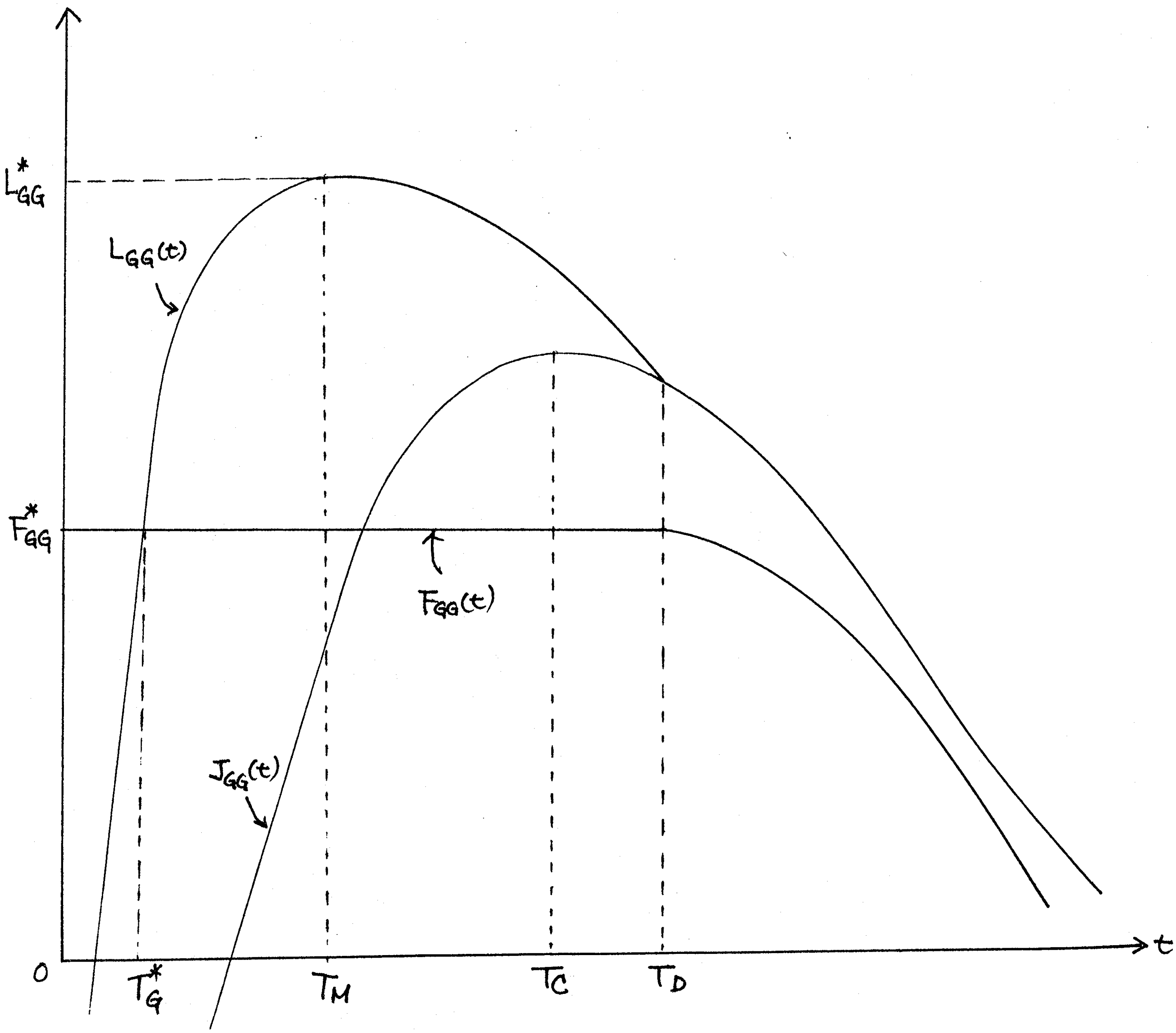

p
1
0
p = β
p = ν(πH, πC) β
p = μ(πH, πC) β
p = (πC/πH) β
p = α(πH, πC) β
Region A
Region B-1
Region B-2
Region B-3
Region C
Region D
β

Figure 3



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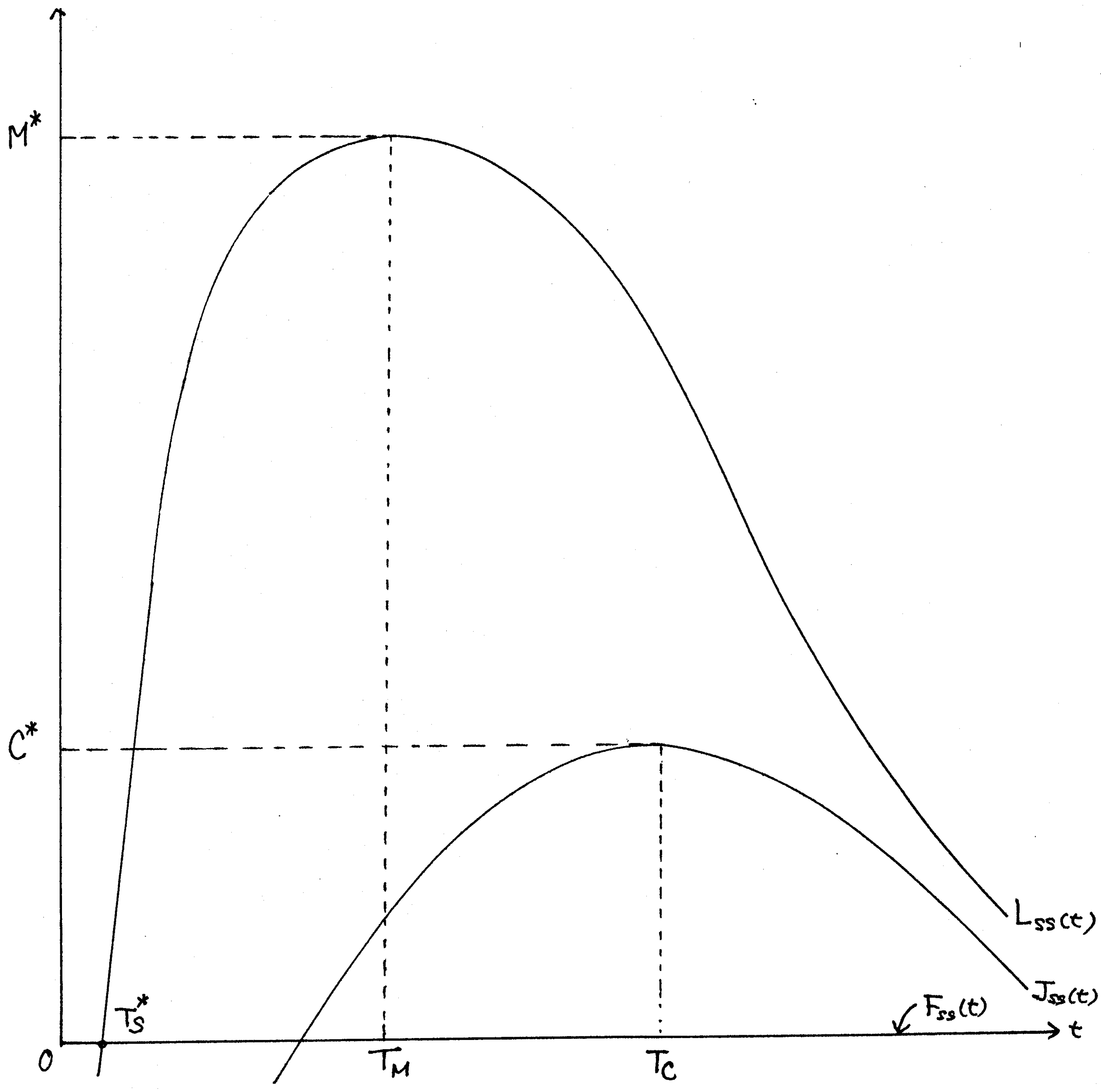

Figure 5

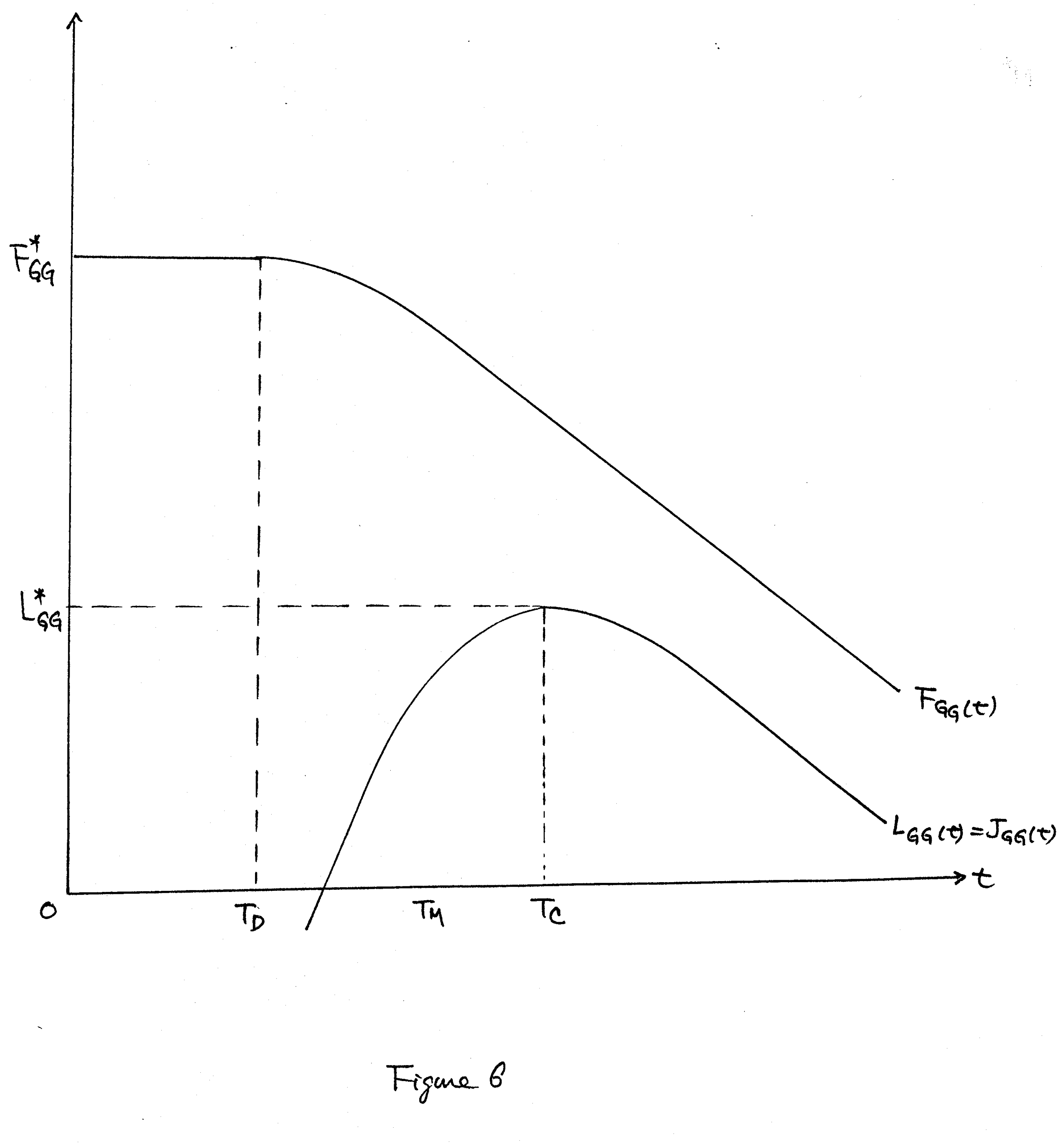

Figure 6

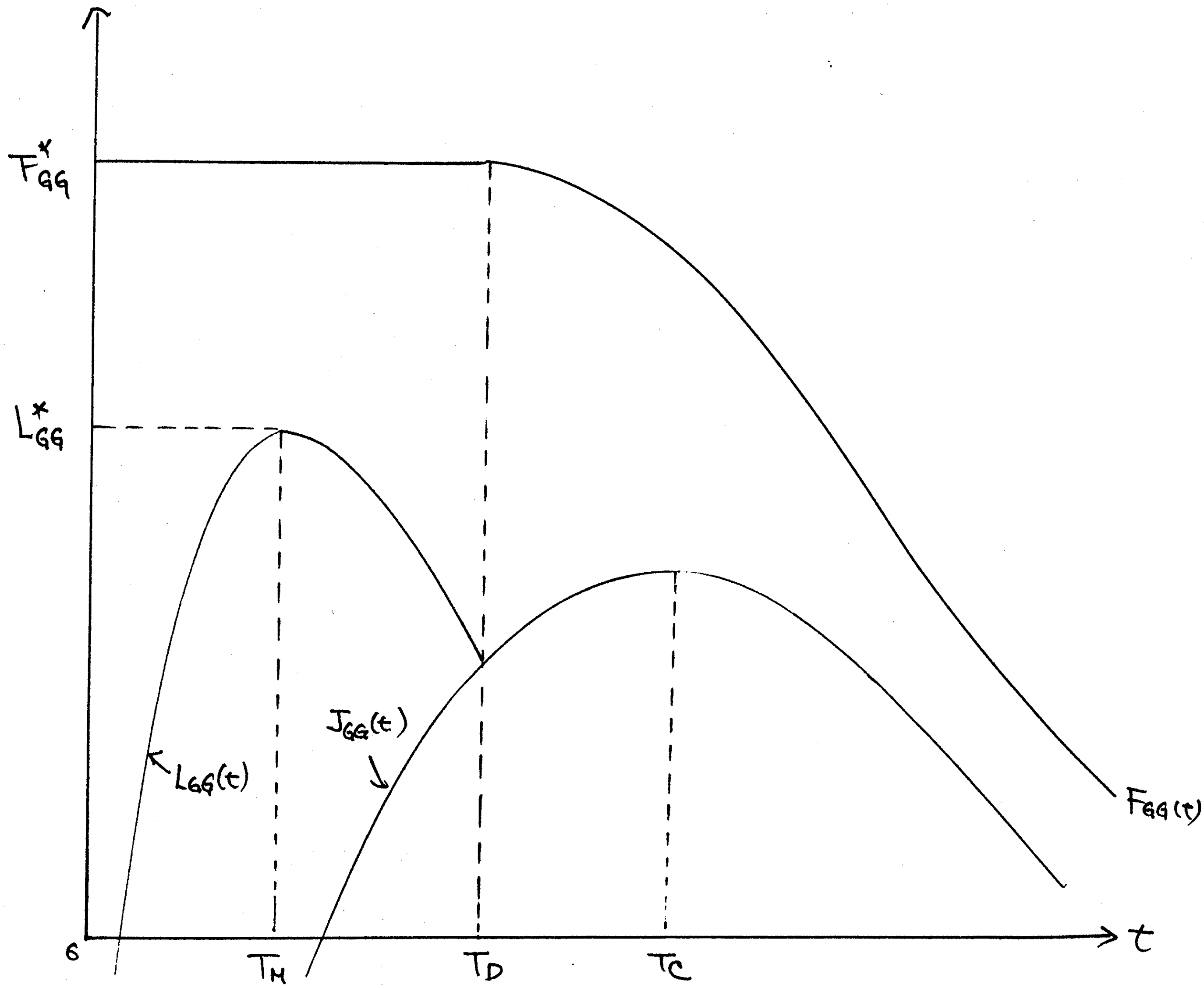

Figure 7