Standing on the Shoulders of Midgets: Dominant Firms and Innovation Incentives

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Abstract. I develop a dynamic innovation model with three important features: (a) asymmetry between large and small firms ("giants" and "midgets"); (b) technology transfer by acquisition; and (c) the distinction between gradual innovation (i.e., within a certain "paradigm") and disruptive innovation (i.e., that which induces a new paradigm). I provide conditions such that (a) greater asymmetry between giant and midget decreases incremental innovation but increases disruptive innovation; and (b) allowing for technology transfer increases incremental innovation but decreases disruptive innovation.

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1. Introduction

As Segal and Whinston (2007) aptly pointed out, "over the last two decades a large share of the economy — the so-called 'new economy' — has emerged ... in which innovation is a critical determinant of competitive outcomes and welfare." A salient feature of many of these industries is the presence of a dominant firm: examples include IBM in the 1980s; Microsoft in the 1990s; Google and Facebook in the 2000s; and Intel since the 1980s. In these industries, the distinction between technology leadership and market leadership becomes relevant. For example, while Intel is clearly the market leader in the microprocessor industry (in terms of production capacity, brand recognition, and so forth), there have been times when AMD has taken the technology lead (in terms of processor speed, for example).

An additional salient feature of many of these industries is the phenomenon of technology transfer — typically by acquisition — which assures the industry leader remains on the technology edge: a significant number of today's most popular and successful products originated with smaller companies which were later gobbled up by one of the big players. A very partial list includes Google acquiring Applied Semantics (Adsense), Android and YouTube; Microsoft acquiring Hotmail and Forethought (Powerpoint); and Facebook acquiring Instagram.

In this setting, two natural questions arise. First, does firm dominance (as in the examples considered above) enhance or hinder innovation? Second, does technology transfer (as in the examples considered above) enhance or hinder innovation? In this paper, I tackle these questions by developing a model of innovation competition with (a) a dominant and a fringe firm; (b) the possibility of technology transfer; and (c) the explicit distinction between incremental and radical innovation.

I define a dominant firm as a one that, for a given technology level, receives greater market payoffs (because, for example, it possesses complementary assets that enhance the value of its technology). Regarding innovation, I assume drastic innovation allows a firm to become the new dominant firm (or keep that position, as the case may be); whereas incremental innovation allows a firm to become a technology leader, within a given dominant firm / fringe firm setting.

I consider an infinite-period innovation game where, in each period, firms (a) receive product market payoffs according to the current industry and technology state; (b) simultaneously choose (at a cost) probabilities of incremental (x) and drastic (y) innovation; and (c) observe the result of their innovation efforts, which in turn leads to a change in state. There are four possible firm states, the cartesian product of industry state (dominant/fringe) and technology state (leader/laggard).[1]

My first set of results deals with the effect of firm dominance on innovation incentives absent the possibility of technology transfer. In this regard, the work by Schumpeter and many other scholars suggests an ambiguous answer: large, dominant firms such as AT&T have been responsible for an important share of innovation during the 20th century; but many new products and services have emerged from small, fringe firms in fragmented industries.

I provide sufficient conditions such that, as the degree of industry dominance increases,

1. As in Aghion et al. (1997) and Segal and Whinston (2007), the latter may be understood as the reduced form of a quality-ladder model with imitation (so that the technology laggard can always move one step behind the technology leader).

the rate of incremental innovation decreases, while the rate of radical innovation increases. The intuition for the latter result is fairly straightforward: increasing the degree of industry dominance increases the prize from becoming a dominant firm, which in turn translates into a greater effort towards radical innovation. In this sense, increasing the degree of industry dominance has an effect similar to an increase in the value of a patent (e.g., an increase in patent length or breath).

The intuition for a decrease in incremental innovation is more complex as there are two effects of opposite sign. First, the dominant firm's incentives increase, as the value of a technology improvement is greater for a bigger firm (a version of the so-called "Arrow" effect; see Arrow, 1962). By the same token, the fringe firm's incentives decrease as its rival's dominance increases (the "shadow of Google" effect). Moreover, convexity of the market profit function (which I assume) implies that, from a static point of view, the encouragement effect is greater than the discouragement effect. A priori, this would suggest a positive net effect; however, in the steady-state the net effect is negative. The reason is that, precisely because the dominant firm is very eager to innovate when it is a technology laggard, the likelihood of being in a state when the industry leader is a technology laggard decreases, so that the dominant-firm encouragement effect is given lower weight.

I next consider the impact of technology transfer. I change the timing of the game by assuming that, in each period, after the outcomes from innovation efforts have been observed, firms have the ability to negotiate a transfer of technology: by paying a transfer price p, the technology laggard becomes a technology leader. I assume efficient bargaining, which implies technology transfer takes place when the industry leader is a technology laggard. I provide sufficient conditions such that technology transfer implies a trade-off between incremental and drastic innovation: compared to the equilibrium with no technology transfer, incremental innovation increases but radical innovation decreases.

The intuition for the increase in incremental innovation is that technology transfer implies that the fringe firm partly internalizes the dominant firm's value from incremental innovation ("innovation for buyout" effect). The intuition for the decrease in drastic innovation is that technology transfer partly levels the equilibrium values of dominant and fringe firms, thus reducing the prize for drastic innovation ("complacency" effect).

Finally, I provide sufficient conditions such that, with technology transfer, an increase in industry dominance results in an increase in both incremental and drastic innovation. Regarding incremental innovation, the intuition is that, because the fringe firm partly internalizes the dominant firm's value from incremental innovation ("innovation for buyout" effect), the discouragement effect previously considered turns into an encouragement effect: the benefits of competing against a big rival decrease as the rival becomes bigger, but the benefits of selling out to a big rival increase as the rival becomes bigger. Regarding drastic innovation, the intuition is similar to the case when technology transfer is absent: an increase in industry dominance increases the prize from innovation.

■ **Literature review.** The literature on innovation is fairly extensive. Reinganum (1989) provides an excellent survey of the work up to the 1980s, including several papers that I will refer to later in the paper. Broadly speaking, the theoretical literature can be classified into three groups. First, one-race timing models such as Loury (1979), Lee and Wilde (1980) or Reinganum (1983). Second, one-race contest models such as Futia (1980), Gilbert and Newbery (1982). And finally, infinite contests (also know as ladder models) such as Harris and Vickers (1987), Aoki (1991), Budd, Harris and Vickers (1993) or Hörner (2004).

Of the more recent literature, Segal and Whinston (2007) is particularly germane. They "study the effects of antitrust policy in industries with continual innovation." Specifically, they consider antitrust policy that changes the relative payoffs of technology leader and laggard. Like them, I find that "conflicting effects" are present in the comparative dynamics analysis of changes in α, the parameter that measures (inversely, in my case) the intensity of antitrust policy. Three important differences of my paper with respect to theirs are that (a) I assume an asymmetric set up where one of the firms is a dominant firm; (b) I consider the possibility of firm acquisition, namely acquisition of a technology leader by a market leader; and (c) I distiguish between incremental and drastic innovation; in fact, one of the important results I develop refers precisely to the trade-off between incremental and drastic innovation.

Aghion et al. (2005) "find strong evidence of an inverted-U relationship between product market competition and innovation." To the extent that an increase in dominant firm's dominance brings industry structure closer to the monopoly extreme, my results provide reasonable conditions under which market power diminishes the overall innovation rate, consistently with Aghion et al. (2005). However, I also provide conditions under which the opposite is true.

My paper is related to a recent literature focusing on technology transfer and markets for technology. Arora et al. (2001) and Gans and Stern (2003) identify the central drivers leading a start-up to either directly commercialize or sell its innovation. They show that one important condition is the efficiency of the "market for ideas." By contrast, I consider the extreme cases when technology transfer is and is not possible. Gans and Stern (2000) analyze the relationship between incumbency and R&D incentives in a framework that combines elements of Gilbert and Newbery (1982) and Reinganum (1983). A key feature of their framework, which I ignore in the present paper, is the possibility of the incumbent threatening to engage in imitative R&D during negotiations for technology transfer.[2] Spulber (2013) studies markets for technology. He argues that competitive pressures increase incentives to innovate. This is consistent with my result regarding the effect of firm dominance on incremental innovation incentives. However, I consider a world where technology transfer results from bilateral negotiation between innovators/competitors, whereas he considers a market for inventions that brings together innovators and competitors. Also related to the issue of technology transfer, Phillips and Zhdanov (2013) "show theoretically and empirically how mergers can stimulate R&D activity of small firms." Although the context of their model is different from mine, my Lemma 3 is consistent with their theoretical and empirical results.

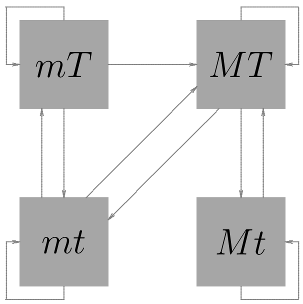
Finally, a related strand of the literature is that dealing with cumulative innovation, including Scotchmer (1991), Green and Scotchmer (1995), and Scotchmer (1996).These papers model cumulative innovation as a two-stage sequence of early and then later innovators. As such, it does not take into account that the technology leaders of today may become technology laggards tomorrow.[3]

The above papers share some of the features of the framework I develop in this paper.

2. See also Gans et al. (2002).

3. The first line in the paper's title is motivated by Scotchmer's (1991) use of Newton's famous adage, as well as Audretsch's variation applied to SBIR, a federal program designed to help small high-tech firms.

Figure 1
State space and state transitions



However, to the best of my knowledge, mine is the first infinite-period innovation model to address simultaneously the issues of firm dominance and technology transfer.[4]

The rest of the paper is organized as follows. Section 2 introduces the model and assumptions. Section 3 presents the results in the case when technology possible is not possible. The technology transfer case is considered in Section 4. Section 5 concludes the paper.

2. Model and assumptions

Consider an industry with two firms and an infinite series of periods $t = 1, 2, ...$ In each period, there is a market dominant firm, which I denote by the subscript M; and a fringe firm, which I denote by the subscript m. As well, there is a technology leader, which I denote by the subscript T; and a technology laggard, which I denote by the superscript t. The cartesian product of these two pairs of possibilities induces four possible states for each firm: $\{MT, Mt, mT, mt\}$, as illustrated by Figure 1.

At the beginning of each period, firms receive product market profits determined by their state: π_{ik}, where $i \in \{M, m\}$ and $k \in \{T, t\}$.[5] Next firms simultaneously spend $C(x_{ik})$ and $D(y_{ik})$ to achieve incremental innovation probability x_{ik} and drastic innovation probability y_{ik}. Finally, Nature determines the outcome of the innovation investments and next period's state is determined. Specifically, I make the following assumptions regarding state transitions:

- If a firm is successful in drastic innovation, then it becomes a dominant firm *and* a technology leader; if both firms are simultaneously successful in drastic innovation, then the previously dominant firm remains dominant.
- If a firm is successful in incremental innovation (and no firm is successful in drastic innovation), then such firm becomes a technology leader; if both firms are simul-

4. There are some additional related papers, including Goettler and Gordon (2011), Hermalin (2013), Rasmusen (1988), that I will refer to later in the paper.
5. Goettler and Gordon (2011) develop a dynamic innovation model and estimate it with data from the personal computer microprocessor industry. A key distinctive feature of their model with respect to mine (and most of the innovation literature) is that they consider the implications of product durability for strategic decisions by buyers. By assuming state-dependent profit values π_{ik} I effectively abstract from issues of durability and strategic buyers.

taneously successful in incremental innovation, then the previous technology leader remains a technology leader.

Figure 1 shows the four possible firm states as well as the possible state transitions (denoted by arrows). For example, a transition from state mt to state mT takes place if and only if (a) no radical innovation takes place; (b) the technology laggard incrementally innovates, whereas (c) the technology leader does not. This implies that the probability of moving from state mt to state mT is given by

$$\mathbb{P}(mT \mid mt) = \big(1 - y_{MT}\big)\big(1 - y_{mt}\big)\,\big(1 - x_{MT}\big)\,x_{mt}$$

The probability of remaining in state MT requires that either (a) the market dominant firm has a drastic innovation; or (b) no firm has a drastic innovation and it is not the case that the technology laggard uniquely incrementally innovates. This implies that the probability of moving from state MT to state MT is given by

$$\mathbb{P}(MT \mid MT) = y_{MT} + \big(1 - y_{mt}\big)(1 - y_{MT})\Big(1 - x_{mt}\,\big(1 - x_{MT}\big)\Big)$$

The probability of moving from state MT to state mt is is the probability that the laggard drastically innovates but the leader does not:

$$\mathbb{P}(mt \mid MT) = \big(1 - y_{MT}\big)\,y_{mt}$$

And so forth. With these transition probabilities at hand, I can derive the firms' value functions v_{ik} recursively. For example,

$$\begin{aligned} v_{MT} = \pi_{MT} - C(x_{MT}) - D(y_{MT}) + \delta\,y_{MT}\,v_{MT} + \delta\,\big(1 - y_{MT}\big)\,y_{mt}\,v_{mt} \\ + \delta\,\big(1 - y_{mt}\big)\big(1 - y_{MT}\big)\,\Big(x_{mt}\,\big(1 - x_{MT}\big)\,v_{Mt} + \Big(1 - x_{mt}\,\big(1 - x_{MT}\big)\Big)\,v_{MT}\Big) \end{aligned}$$

I look for symmetric Markov equilibria, defined by firm strategies (x_{ik}, y_{ik}) and value functions v_{ik} that satisfy the Bellman optimality principle. For example, in state

$$\begin{aligned} x_{MT} &= \breve{C}\Big(\delta\,\big(1 - y_{mt}\big)\big(1 - y_{MT}\big)\;x_{mt}\,(v_{MT} - v_{Mt})\Big) \\ y_{MT} &= \breve{D}\Big(\delta\,y_{mt}\,(v_{MT} - v_{mt}) + \delta\,\big(1 - y_{mt}\big)\;x_{mt}\,\big(1 - x_{MT}\big)\,(v_{MT} - v_{Mt})\Big) \end{aligned}$$

where $\breve{C}$ and $\breve{D}$ are the inverse of C' and D', respectively.

■ **Innovation rates.** From a firm's point of view, there are four different states. From society's point of view, however, there are only two different states. Specifically, denote by 1 the state when the market leader is also the technology leader; and by 0 the state when the market leader is the technology laggard. Incremental and drastic innovation rates at each state are given by

$$\begin{aligned} X_1 &= 1 - \big(1 - x_{mt}\big)\,\big(1 - x_{MT}\big) \\ X_0 &= 1 - \big(1 - x_{mT}\big)\,\big(1 - x_{Mt}\big) \\ Y_1 &= 1 - \big(1 - y_{mt}\big)\,\big(1 - y_{MT}\big) \\ Y_0 &= 1 - \big(1 - y_{mT}\big)\,\big(1 - y_{Mt}\big) \end{aligned} \tag{1}$$

For example, X_1 is the complement of the probability that no firm innovates, that is, $\left(1 - x_{mt}\right)\left(1 - x_{MT}\right)$, when we are in state M (the market leader is also the technology leader).

Let m_s be the probability of transition to state s, where $s = \{0, 1\}$; and let μ be the steady-state probability of being in state 1. Then the steady-state innovation rates are given by

$$\begin{aligned} X &\equiv \mu\, X_1 + (1-\mu)\, X_0 \\ Y &\equiv \mu\, Y_1 + (1-\mu)\, Y_0 \end{aligned} \tag{2}$$

The focus of the paper is precisely on understanding the comparative statics of X and Y, the steady-state rates of incremental and drastic innovation, respectively.

■ **Functional-form assumptions.** In an effort to make my results as little dependent on functional forms as possible, I make relatively minimal assumptions regarding functional forms. First, I make the following assumption regarding the cost functions $C(x), D(y)$:

Assumption 1. *(a) $C(x), D(y)$ are of class C^3; (b) $C(0) = D(0) = 0$; (c) $C'(0) = D'(0) = 0$; (d) $C''(x), D''(x) > 0$; (e) $\lim_{x\to 1} C'(x) = \lim_{y \to 1} D'(x) = \infty$*

For simplicity, I will use the notation $\phi_C \equiv 1/C''(0)$ and $\phi_D \equiv 1/D''(0)$. These parameters measure how easy it is to induce incremental and drastic innovation, respectively. Consider for example ϕ_C. By part (c) of Assumption 1, some positive incremental-innovation effort is optimal. If $C''(0)$ is very high, then ϕ_C is very low: as x increases, the marginal cost of incremental innovation increases very rapidly. We thus expect the optimal value of x to be lower (all else equal). The same reasoning applies to ϕ_D and the optimal level of y.

Regarding product market payoffs, I make the following assumptions:

Assumption 2. $\pi_{iT} > \pi_{it}$

In words, technology leadership is profitable, regardless of whether a firm is market dominant or not (as indicated by $i \in \{M, m\}$). Finally, the next assumption puts some meat on the concept of market dominance. Specifically, suppose that the parameter α measures the degree of market dominance, as follows:

Assumption 3. *(a) $\pi_{ik} = \pi_{jk}$ if $\alpha = 0$; (b) π_{Mk} is increasing in α and π_{mk} is decreasing in α; (c) $\left(\pi_{MT} - \pi_{Mt}\right)$ is increasing in α and $\left(\pi_{mT} - \pi_{mt}\right)$ is decreasing in α; (d) $\left|\, d\left(\pi_{MT} - \pi_{Mt}\right)/d\alpha \,\right| \;>\; \left|\, d\left(\pi_{mT} - \pi_{mt}\right)/d\alpha \,\right|$*

(Not all conditions not necessary for all of the results that follow.)

■ **Numerical computation.** The dynamic game under consideration is highly non-linear, and admits no general closed-form analytical solution. My strategy is to linearize the system of value functions and first-order conditions around $\delta = 0$. Since I can easily solve for the unique equilibrium when $\delta = 0$ and show that the implicit function theorem applies at $\delta = 0$, I can apply Taylor's theorem and obtain analytical results valid for the unique equilibrium in the neighborhood of $\delta = 0$. I then use numerical methods to solve the model for higher values of δ and confirm that the analytical results obtained in the neighborhood of $\delta = 0$ extend (in a qualitative sense) to higher values of δ.[6]

For the purpose of numerical computation, I assume the cost functions are given by

$$C(x) = \gamma_C\big(-\ln(1-x) - x\big)$$
$$D(y) = \gamma_D\big(-\ln(1-y) - y\big)$$

These functional forms have the desirable properties that marginal cost is zero at zero innovation probability and infinity at probability-one innovation probability.

Regarding the product market functions, I consider the following product market model. There exists a continuum of consumers (normalized to a measure 1), each of whom buys one unit from firm M *or* from firm m. Specifically, each consumer receives net utility u_i from purchasing from firm i ($i = M, m$):

$$u_i = \lambda_i + \alpha_i - p_i + \zeta_i \tag{3}$$

where λ_i denotes firm i's technology leadership, α_i denotes firm i's industry leadership, p_i is firm i's price, and ζ_i is the consumer's utility shock from buying firm i's product. Specifically, $\lambda_i = \lambda$ if firm i is the technology leader, $\lambda_i = 0$ otherwise; and similarly, $\alpha_i = \alpha$ if firm i is the industry leader (that is, $i = M$), $\alpha_i = 0$ otherwise.

Suppose ζ_i is sufficiently large that the market is covered, that is, the outside option is always dominated by either firm M or firm m. Given that, I work with $\xi \equiv \zeta_i - \zeta_j$, the consumer's relative preference for firm i. I further assume ξ_i is distributed according to a normal $N(0, \sigma^2)$; and, with no further loss of generality, assume $\sigma^2 = 1$.

It can be shown that the above functional forms satisfy Assumptions 1–3.

3. Results

As I mentioned earlier, while a general analytical solution to the model is not possible, I am able to characterize the dynamic system in the neighborhood of $\delta = 0$ (cf Budd et al., 1993).

Lemma 1. *In the neighborhood of $\delta = 0$ and for $i \in \{M, m\}$, $k \in \{T, t\}$,*

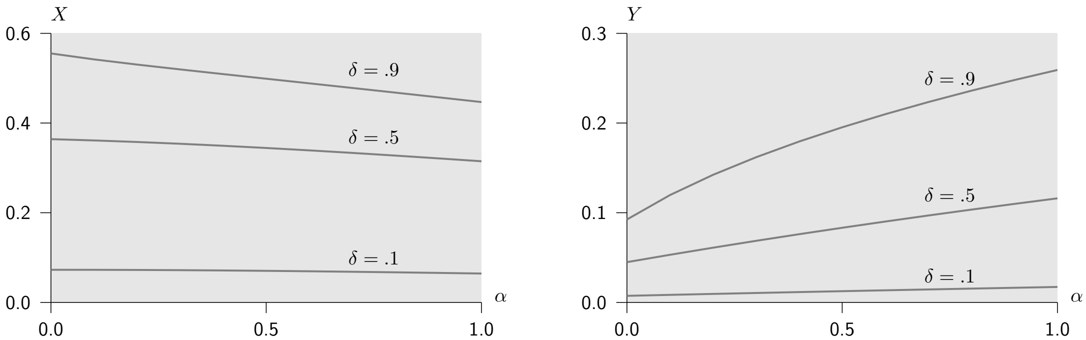
$$x_{ik} \approx \phi_C(\pi_{iT} - \pi_{ik})$$
$$y_{ik} \approx \phi_D(\pi_{MT} - \pi_{ik})$$

where the difference between the approximation and the exact value is of order $\mathbb{O}(\delta^2)$.

Lemma 1 implies that $x_{iT} \approx 0$ and $y_{MT} \approx 0$. The intuition for this is to be found in the well-known replacement effect in innovation games (Arrow, 1962; Reinganum, 1983). Consider for example the case of incremental innovation. If $\delta \approx 0$, then the likelihood that a firm innovates is small. For a technology leader, this implies that the benefits from innovation are very small: the most likely event is that, if the technology leader innovates, it will replace a leadership position with another leadership position. A similar reasoning applies to drastic innovation.

6. As often is the case with this type of models, I have no analytical uniqueness result. I try multiple starting values and convergence algorithms and always obtain the same equilibrium.

Figure 2
Firm dominance and innovation



Lemma 2. *In the neighborhood of $\delta = 0$,*

$$X \approx \frac{(y_{mT} + x_{Mt})\; x_{mt} + (y_{mt} + x_{mt})\; x_{Mt}}{y_{mt} + x_{mt} + y_{mT} + x_{Mt}}$$
$$Y \approx \frac{(y_{mT} + x_{Mt})\; y_{mt} + (y_{mt} + x_{mt})\; y_{mT}}{y_{mt} + x_{mt} + y_{mT} + x_{Mt}}$$

where the difference between the approximation and the exact value is of order $\mathbb{O}(\delta^2)$.

Lemmas 1 and 2 allow me to characterize the impact of firm dominance on incremental and drastic innovation. Part of the next result depends on the condition that

$$(\pi_{MT} - \pi_{Mt})^2\ \frac{d(\pi_{mT} - \pi_{mt})}{d\alpha} + (\pi_{mT} - \pi_{mt})^2\ \frac{d(\pi_{MT} - \pi_{Mt})}{d\alpha} < 0 \qquad (4)$$

While I have not been able to find general results regarding this condition, all functional forms I have considered satisfy it (including, in particular, normal and uniform preference shocks).

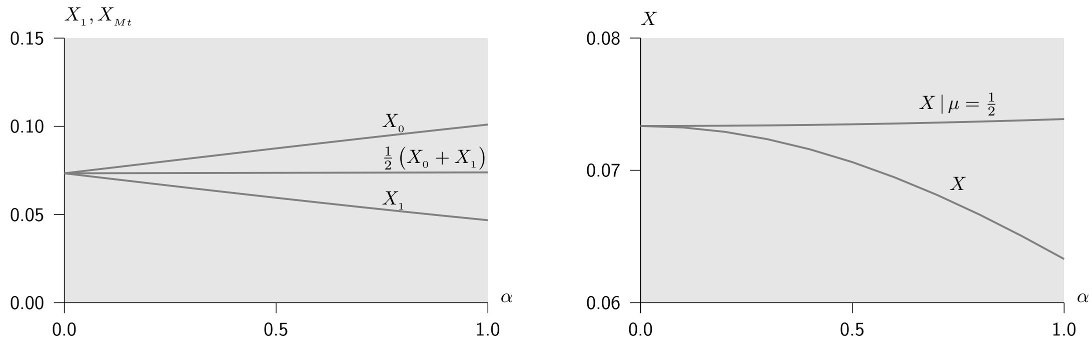
Proposition 1. *There exists a $\overline{\delta}$ such that, if $\delta < \overline{\delta}$, then*

- *There exists a $\overline{\phi}_C$ such that, if $\phi_C < \overline{\phi}_C$, then the steady-state incremental-innovation rate, X, is decreasing in the degree of market dominance α if and only if (4) holds.*
- *There exist a $\overline{\overline{\phi}}_D$ such that, if $\phi_D > \overline{\overline{\phi}}_D$ and $\delta < \overline{\delta}$, then the steady-state radical-innovation rate, Y, is increasing in the degree of market dominance α.*

Note that the above (analytical) result is only valid in the neighborhood of $\delta = 0$. Figure 2 plots the value of X and Y as a function of α for higher values of δ. The numerical results confirm the signs predicted by Proposition 1.

The intuition for the first part of Proposition 1 proceeds in three steps. First, if δ is small then the replacement effect is very strong for technology leaders: since equilibrium innovation rates are small, the most likely outcome of innovation for a technology leader is to stay in the same position: its innovation will be imitated by the rival and the distance between technology leader and technology laggard remains fixed. Given this replacement effect, the relevant innovation incentives correspond to those of technology laggards.

Figure 3
Encouragement and discouragement effects ($\delta = .1$)



Second, the innovation incentives for a technology laggard are proportional to $\pi_{iT} - \pi_{it}$. Not only is this greater for the market dominant firm, but also it increases with α at a higher rate for the market dominant firm. This follows from convexity of product-market profits and corresponds to the intuition that a market dominant firm has more to gain from innovation (that is, the combination of market dominance and technology dominance is supermodular). In other words, the encouragement effect of market dominance (market leader has a lot to gain) outweighs the discouragement effect of market dominance (market laggard has little to gain).

Third, along the steady-state the probability that the market leader is the technology laggard decreases as α increases. In words, because of the previous effect (encouragement/discouragement effect), the weight placed on the encouragement effect decreases and the weight placed on the discouragement effect increases. In fact, the steady-state probability attached to the state where the market leader is the technology leader is proportional to the market leader's innovation probability when a technology laggard.

Finally, the "intensive margin" and the "extensive margin" effects work in opposite ways in terms of the steady-state innovation probability. For normal and uniform preference shocks, it can be shown that the "extensive margin" effect dominates, so that the innovation probability declines.

To put it differently, differentiating the first equation in (2) with respect to α we get

$$\underbrace{\frac{dX}{d\alpha}}_{<0} = \underbrace{\mu \frac{dX_1}{d\alpha} + (1-\mu)\frac{dX_0}{d\alpha}}_{>0} + \underbrace{\frac{d\mu}{d\alpha}}_{>0} \underbrace{\left(X_1 - X_0\right)}_{<0}$$

In the neighborhood of $\delta = 0$, the first two terms on the right-hand side have opposite sign. The positive term outweighs the negative one, so the net sum is positive. However, the third term is negative and outweighs the net sum of the first two terms.

Figure 3 restates the same ideas in a different way. The left panel shows how X_0 and X_1 vary with respect to α. As mentioned earlier, an increase in firm dominance (and increase in α) implies an encouragement effect (higher effort when industry leader is a technology laggard, which corresponds to an increase in X_0); but it also implies a discouragement effect (lower effort when fringe firm is a technology laggard, which corresponds to a decrease in

X_1). If we give both effects equal weight, they approximately cancel out, so as shown by the left panel (if $\delta = 0$, then they exactly cancel out).

However, for positive values of δ and as α increases, the equilibrium weight placed on X_0 becomes lower, whereas the equilibrium weight placed on X_1 becomes higher; and the net effect is negative. The right panel in Figure 3 illustrates this phenomenon. If we fix the steady-state probability of states X_0 and X_1 to be $\frac{1}{2}$, then an increase in α leads to an increase in X. However, if we take into account the endogenous change in μ the effect on X of an increase in α is negative.

4. Technology transfer

A significant number of today's most popular and successful products originated with smaller companies which were later gobbled up by one of the big players (Google, Microsoft, Yahoo, IBM, Oracle, etc). A very partial list includes Google acquiring Applied Semantics (Adsense), Android and YouTube; Microsoft acquiring Hotmail and Forethought (Powerpoint); and Facebook acquiring Instagram. These examples motivate a natural question: how are innovation incentives shaped by the possibility of innovator acquisition? And given that firm acquisition is possible, how does an increase in market dominance affect industry innovation incentives?

I now change the model to allow for the possibility of technology transfer. Specifically, I assume that, after innovation outcomes are known and before the next period begins, firms Nash bargain over transfer of technology (that is, bargaining is efficient and the gains from an agreement are equally split among the two parties).[7] Efficient bargaining implies that technology transfer takes place if and only if the sum of the two firms' value functions increases as a result of technology transfer. This happens in state 0 but not in state 1.

Let p be the transfer price in state 0. Nash bargaining implies that transfer price is given by

$$\max_{p} \; (v_{MT} - p - v_{Mt})\,(v_{mt} + p - v_{mT})$$

which implies

$$\widehat{p} = \tfrac{1}{2}(v_{MT} - v_{Mt} + v_{mT} - v_{mt})$$

Let u_{ik} be the firm interim value just before technology transfer negotiations take place. We then have

$$\begin{aligned} u_{mT} &= v_{mt} + \widehat{p} \\ u_{Mt} &= v_{MT} - \widehat{p} \end{aligned}$$

and $u_{ik} = v_{ik}$ for all other values of i, k.

The value functions are similar to the case of no technology transfer. The main difference is that, when the innovation outcome shows the dominant firm as technology laggard, we

7. I am particularly interested in examining the effects of technology transfer on innovation incentives. For this reason, I consider a rather simple model of technology transfer. Hermalin (2013) models explicitly the relation between buyer and seller when there is asymmetric information and moral hazard.

use u_{ik} as continuation value, rather than v_{ik}. For example,

$$\begin{aligned} v_{MT} &= \pi_{MT} - C(x_{MT}) - D(y_{MT}) + \delta\, y_{MT}\, v_{MT} + \delta\,(1 - y_{MT})\, y_{mt}\, v_{mt} \\ &\quad + \delta\,(1 - y_{mt})(1 - y_{MT}) \Big(x_{mt}\,(1 - x_{MT})\, u_{Mt} + \big(1 - x_{mt}\,(1 - x_{MT})\big)\, v_{MT} \Big) \end{aligned}$$

where

$$u_{Mt} = v_{MT} - \widehat{p} = \tfrac{1}{2}\,(\pi_{MT} + \pi_{Mt} - \pi_{mT} + \pi_{mt})$$

Lemma 3. *In the neighborhood of $\delta = 0$ and for $i, j \in \{M, m\}$, $k, \ell \in \{T, t\}$, $j \neq i$, $\ell \neq k$,*

$$\begin{aligned} x_{ik} &\approx \tfrac{1}{2}\,\phi_C\,(\pi_{MT} + \pi_{mT} - \pi_{Mk} - \pi_{mk}) \\ y_{ik} &\approx \tfrac{1}{2}\,\phi_D\,(\pi_{MT} - \pi_{mt} - \pi_{ik} + \pi_{j\ell}) \end{aligned}$$

where the difference between the approximation and the exact value is of order $\mathbb{O}(\delta^2)$.

Let Δx_{ik} be the difference in x_{ik} between the cases with and without technology transfer when $\delta \approx 0$, likewise for Δy_{ik}. Lemmas 1 and 3 imply

$$\Delta x_{it} \approx \tfrac{1}{2}\,\phi_C\,(\pi_{MT} + \pi_{mT} - \pi_{Mt} - \pi_{mt}) - \phi_C(\pi_{iT} - \pi_{it}) = \tfrac{1}{2}\,\phi_C\,\big(\pi_{jT} - \pi_{iT} + \pi_{it} - \pi_{jt}\big)$$

where $\approx$ means that the difference with respect to the actual values is of the same order as δ^2. Assumption 3 implies that

$$\begin{aligned} \Delta x_{MT} &\approx \Delta x_{mT} \approx 0 \\ \Delta x_{mt} &\approx \tfrac{1}{2}\,\phi_C\,(\pi_{MT} - \pi_{Mt}) - \tfrac{1}{2}\,\phi_C\,(\pi_{mT} - \pi_{mt}) > 0 \\ \Delta x_{Mt} &\approx -\Delta x_{mt} < 0 \end{aligned}$$

In words, the prospect of technology transfer increases the fringe firm's incremental innovation incentives and decreases the dominant firm's incentives by approximately the same amount. Similar computations establish that

$$\begin{aligned} \Delta y_{MT} &\approx \Delta y_{mt} \approx 0 \\ \Delta y_{Mt} &\approx \Delta y_{mT} \approx \tfrac{1}{2}\,\phi_D\,(\pi_{mT} - \pi_{mt}) - \tfrac{1}{2}\,\phi_D\,(\pi_{MT} - \pi_{Mt}) < 0 \end{aligned}$$

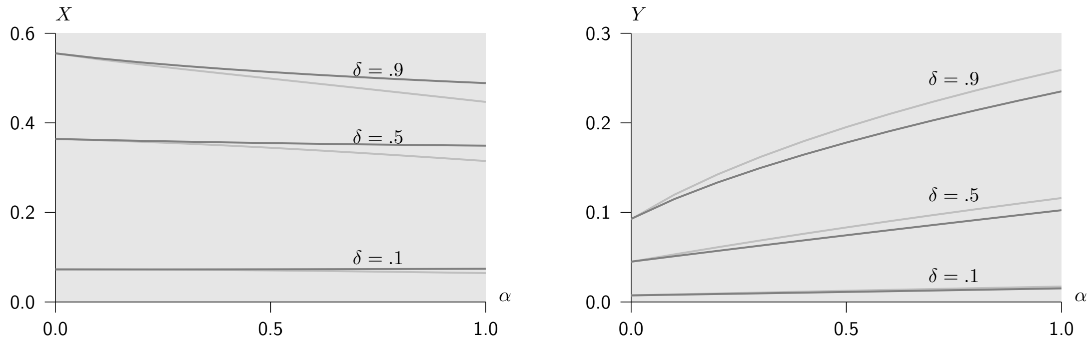
The next result derives implications in terms of the steady-state rate of incremental and radical innovation.

Proposition 2. *There exists $\overline{\delta}$ such that, if $\delta < \overline{\delta}$, then allowing for technology transfer implies an increase in the steady-state incremental innovation rate, X, and a decrease in the steady-state drastic innovation rate, Y.*

In a related paper, Rasmusen (1988) shows that the possibility of buyout can make entry profitable which otherwise would not be. In other words, the possibility of firm acquisition increases entry incentives. Similarly, Proposition 2 implies that the possibility of firm acquisition increases incremental innovation incentives.

I now turn to the issue of market dominance and innovation incentives. Intuitively, there are two effects at play: on the one hand, an increase in market dominance increases the relative bargaining power of firm a with respect to the innovator; on the other hand, an increase in market dominance increases firm a's valuation for the innovation. Which effect dominantes?

Figure 4
Firm dominance and innovation



Proposition 3. *Suppose technology transfer is possible. There exists $\overline{\delta}$ such that, if $\delta < \overline{\delta}$ then*

- *The steady-state incremental innovation rate, X, increases as the degree of firm dominance α increases.*
- *There exists $\overline{\phi}_D(\delta)$ such that, if $\phi_D > \overline{\phi}_D$, then the steady-state drastic innovation rate, Y, increases as the degree of firm dominance α increases.*

Figure 4 illustrates both Propositions 2 and 3. The lighter lines correspond to the equilibrium without technology transfer, whereas the darker lines correspond to the case with technology transfer. Although Proposition 2 is limited to the case when δ lies in the neighborhood of 0, we see that the qualitative nature of the results — that technology transfer increases incremental innovation but decreases radical innovation — also holds for higher values of δ. The idea is that, upon innovation, a fringe firm that is a technology laggard captures a higher value than it would absent technology transfer. This leads to an increased incentive for incremental innovation. But technology transfer has an additional effect: it increases the relative payoff of a fringe firm vis-a-vis a dominant firm. By doing so, it decreases the former's incentive for radical innovation. I call this the "complacency" effect: technology transfer makes the current state of industry dominance too attractive for the fringe firm.

Proposition 3 states that, with technology transfer (darker lines in Figure 4) and when $\delta \approx 0$, both incremental as drastic innovation increase as the degree of industry dominance (α) increases. The two panels in Figure 4 confirm this prediction when $\delta = .1$. For higher values of δ, the relation between α and Y holds. However, for higher values of δ, X turns from increasing to decreasing in α. The intuition is that there are two conflicting effects. First, with technology transfer firms partially internalize the joint payoff from innovation; and an increase in α increases joint payoff. But second, as we saw before an increase in α implies that, along the steady-state, it's more common for the fringe firm to be the technology laggard; and for such firm an increase in α dampens incentives for incremental innovation.

■ **Leadership persistence.** One of the central issues in the innovation literature is the degree to which leaders tend to remain as leaders, as opposed to being replaced by catching-up or leap-frogging laggards. Arrow (1962) and Reinganum (1983) emphasize the importance of the replacement effect: to the extent that technology leaders would be cannibalizing their own product by producing a new one, laggards are more likely to innovate than leaders. Lemma 1 is consistent with this view: it shows that, in the neighborhood of $\delta = 0$, the technology leader's innovation effort is close to zero, whereas the technology laggard's is of positive order. As a result, conditional on innovation taking place, the expected motion of the system is for the technology laggard to leapfrog the technology leader.

Gilbert and Newbery (1982) point to a different effect (sometimes referred to as the efficiency effect or the joint-profit effect). If a given innovation were to be appropriated by the technology leader *or* by the technology laggard (e.g., sold in an auction), then the technology leader would have more to lose from not appropriating that innovation than the technology laggard. As such, we would expect that the technology leader would end up owning the innovation. The analysis in Section 4 is consistent with this view: if the fringe firm produces an incremental innovation while technology laggard, then efficient bargaining implies that the innovation is transferred to the dominant firm, thus implying persistence of technology leadership (conditional on no radical innovation taking place).

To put it differently, the possibility of technology transfer separates the question of "who innovates" from the question of "who is the technology leader" (in the sense of owning the leading technology). The replacement effect implies that technology laggards are more likely to innovate; but the efficiency effect implies that market leaders are more likely to persist as technology leaders.

5. Concluding remarks

Sir Isaac Newton famously stated that, "if I have seen far, it is by standing on the shoulders of giants." Many recent examples from high-tech industries suggest that the opposite may be true, that it's a case of "giants standing on the shoulders of midgets." In this paper, I considered two versions of this phenomenon: imitation and acquisition. The first version is the phenomenon whereby small firms invent only to see their ideas copied by "giants" who leverage their market power to effectively appropriate the value generated by "midgets." The second version is the phenomenon whereby small inventors ("midgets") are gobbled up by dominant firms ("giants").[8]

If there is no technology transfer, then an increase in industry dominance leads to a decrease in incremental innovation and an increase in drastic innovation. The increase in drastic innovation follows from a simple argument: the bigger a giant is, the bigger the incentive to become a giant (which in my model happens by means of drastic innovation).

Regarding incremental innovation, there are two effects of opposite sign: an increase in industry dominance increases the dominant firm's innovation incentives (a sort of "Arrow effect") but decreases the fringe firm's incentives (a sort of negative "Arrow effect"). I show that, in absolute value, the encouragement effect is greater than the discouragement effect; but along the steady-state, the discouragement effect is more often relevant than the encouragement effect, so that, all in all, firm dominance has a negative effect on incremental innovation.

The possibility of technology transfer changes the comparative statics considerably. First, technology transfer leads firms to internalize innovation externalities (an effect similar

8. A third possible version of "standing on the shoulders of" is the phenomenon of follow-up innovation. See Scotchmer (1991), Green and Scotchmer (1995), and Scotchmer (1996).

to the "Grossman-Hart effect" of investment externalities). This in turn has a positive effect on incremental innovation. Second, and precisely as a result of the "internalization" effect, the rate of drastic innovation decreases when technology transfer is possible. Intuitively, to the extent that the fringe firm's payoffs increase, its incentives to become a dominant firm decrease (a sort of negative "Arrow replacement effect").

Finally, given technology transfer, an increase in firm dominance leads to an increase in incremental and drastic innovation. The positive effect on drastic innovation has the same explanation as before (bigger prize, bigger incentive). The positive effect on incremental innovation results from the internalization by the fringe firm of the added benefits by the dominant firm.

My results have potentially important antitrust implications, namely policy with respect to dominant firms. Is market dominance good for innovation? Frequently, the analysis of market dominance and abuse of market dominance is framed in a static context, or at least in the context of a given set of products. In highly innovative industries, however, the effect of antitrust on innovation becomes of primary importance. It has been remarked that

> In some niches of the software business, Google is casting the same sort of shadow over Silicon Valley that Microsoft once did. "You've got people who don't even feel they can launch a product for fear that Google will get in."[9]

I showed that this view has merit (see the first part of Proposition 1) but is incomplete. First, Google's innovation incentives are greater the greater Google is.[10] Second, if technology transfer is possible then small innovators benefit from a bigger Google as they are more likely to be bought by a high price (the "innovation for buyout" effect). Finally, a competition policy that allows for large "Googles" increases the incentives to become the next Google. In this sense, a pro-dominant-firm competition policy is a substitute for a pro-innovator IP policy (e.g., strong patents).

There are a number of possible extensions to my framework, from which I select two. In this section, I consider a series of possible extensions of my basic framework: number of firms and bargaining frictions. When we think of a dominant firm, we think of an industry with a large firm and a large number of small firms. Specifically, an alternative model would have, in each period, one M firm and N m firms, or one T firm and N t firms. In this context, an interesting application would be horizontal merger analysis: a (Mt,mt) merger would correspond as an increase in α; a (mt,mt) merger would correspond to a decrease in α; and a (Mt,mT) merger would have implications similar to allowing for technology transfer.

In my model of technology transfer I assume efficient bargaining. However, Galasso and Schankerman (2015)'s work on the value of patents suggests that bargaining frictions are greater when the asymmetry between buyer and seller is greater. Also, anecdotal evidence suggests that negotiations do not always result in technology transfer. For example, Google acquired Applied Semantics to get Adsense. Google also attempted to to acquire Idealab, but the target did not sell. As a result, Google imitated Idealab, the latter sued and the IP issues were settled in court.

9. "Microsoft And Google Set to Wage Arms Race," by Steve Lohr and Saul Hansell, *The New York Times*, May 2, 2006.

10. Microsoft's defense in the 1998 DOJ case was partially based on the idea that, precisely because Microsoft was dominant, it was "paranoid" about the possibility of rival innovation (i.e., Microsoft had a lot to lose), therefore it had to innovate more.

If there are bargaining frictions and these are greater the greater the asymmetry between buyer and seller, then an increase in α, in addition to the effects considered in the previous sections, would also increase bargaining frictions. Specifically, suppose that, with probability β, negotiations break down and no technology transfer takes place. My results remain valid (in qualitative terms) so long as *the derivative* of β with respect to α is not too high.

I have also assume that buyer and seller split gains 50-50. This is not an important assumption. The qualitative results hold if the dominant firm gets a share ψ of the pie, where $\psi \in (0, 1)$. As in the case of β, the important assumption is that the derivative of ψ with respect to α is not very different from zero.

Appendix

Proof of Lemma 1: The value functions in each possible state are given by

$$
\begin{aligned}
v_{MT} &= \pi_{MT} - C(x_{MT}) - D(y_{MT}) + \delta\, y_{MT}\, v_{MT} + \delta\,(1-y_{MT})\, y_{mt}\, v_{mt} \\
&\quad + \delta\,(1-y_{mt})(1-y_{MT})\,\Big(x_{mt}\,(1-x_{MT})\, v_{Mt} + (1 - x_{mt}\,(1-x_{MT}))\, v_{MT}\Big) \\
v_{Mt} &= \pi_{Mt} - C(x_{Mt}) - D(y_{Mt}) + \delta\, y_{Mt}\, v_{MT} + \delta\,(1-y_{Mt})\, y_{mT}\, v_{mt} \\
&\quad + \delta\,(1-y_{mT})(1-y_{Mt})\,\Big(x_{Mt}\,(1-x_{mT})\, v_{MT} + (1 - x_{Mt}\,(1-x_{mT}))\, v_{Mt}\Big) \\
v_{mT} &= \pi_{mT} - C(x_{mT}) - D(y_{mT}) + \delta\, y_{Mt}\, v_{mt} + \delta\,(1-y_{Mt})\, y_{mT}\, v_{MT} \\
&\quad + \delta\,(1-y_{Mt})(1-y_{mT})\,\Big(x_{Mt}\,(1-x_{mT})\, v_{mt} + (1 - x_{Mt}\,(1-x_{mT}))\, v_{mT}\Big) \\
v_{mt} &= \pi_{mt} - C(x_{mt}) - D(y_{mt}) + \delta\, y_{MT}\, v_{mt} + \delta\,(1-y_{MT})\, y_{mt}\, v_{MT} \\
&\quad + \delta\,(1-y_{MT})(1-y_{mt})\,\Big(x_{mt}\,(1-x_{MT})\, v_{mT} + (1 - x_{mt}\,(1-x_{MT}))\, v_{mt}\Big)
\end{aligned}
$$

The first-order conditions for optimal investment in incremental innovation are given by

$$
\begin{aligned}
x_{MT} &= \breve{C}\Big(\delta\,(1-y_{mt})(1-y_{MT})\; x_{mt}\,(v_{MT}-v_{Mt})\Big) \\
x_{Mt} &= \breve{C}\Big(\delta\,(1-y_{mt})(1-y_{MT})\;(1-x_{mT})\,(v_{MT}-v_{Mt})\Big) \\
x_{mT} &= \breve{C}\Big(\delta\,(1-y_{mt})(1-y_{MT})\; x_{Mt}\,(v_{mT}-v_{mt})\Big) \\
x_{mt} &= \breve{C}\Big(\delta\,(1-y_{mt})(1-y_{MT})\;(1-x_{MT})\,(v_{mT}-v_{mt})\Big)
\end{aligned}
\tag{5}
$$

The first-order conditions for optimal investment in drastic innovation are given by

$$
\begin{aligned}
y_{MT} &= \breve{D}\Big(\delta\, y_{mt}\,(v_{MT}-v_{mt}) + \delta\,(1-y_{mt})\; x_{mt}\,(1-x_{MT})\,(v_{MT}-v_{Mt})\Big) \\
y_{Mt} &= \breve{D}\bigg(\delta\, y_{mT}\,(v_{MT}-v_{mt}) + \delta\,(1-y_{mT})\,\Big(1 - x_{Mt}\,(1-x_{mT})\Big)\,(v_{MT}-v_{Mt})\bigg) \\
y_{mT} &= \breve{D}\bigg(\delta\,(1-y_{Mt})\,\Big(v_{MT} - x_{Mt}\,(1-x_{mT})\, v_{mt} - \Big(1 - x_{Mt}\,(1-x_{mT})\Big)\, v_{mT}\Big)\bigg) \\
y_{mt} &= \breve{D}\bigg(\delta\,(1-y_{Mt})\,\Big(v_{MT} - x_{mt}\,(1-x_{MT})\, v_{mT} - \Big(1 - x_{mt}\,(1-x_{MT})\Big)\, v_{mt}\Big)\bigg)
\end{aligned}
\tag{6}
$$

Define, for a generic variable z,

$$
\widehat{z} \equiv z\,\big|_{\,\delta\,=\,0} \qquad \dot{z} \equiv \frac{\partial z}{\partial \delta}\,\bigg|_{\,\delta\,=\,0}
$$

Taking derivatives of the value functions and first-order conditions with respect to δ and substituting $\delta = 0$, we get

$$
\begin{aligned}
&\widehat{x}_{ik} = 0, \\
&\widehat{y}_{ik} = 0 \\
&\widehat{v}_{ik} = \pi_{ik}
\end{aligned}
$$

$$
\begin{aligned}
\dot{v}_{ik} &= \pi_{ik} \\
\dot{x}_{ik} &= \breve{C}'(0)\left(\widehat{v}_i^T - \widehat{v}_{ik}\right) = \phi_C\left(\pi_i^T - \pi_{ik}\right) \\
\dot{y}_{ik} &= \breve{D}'(0)\left(\widehat{v}_{MT} - \widehat{v}_{ik}\right) = \phi_D\left(\pi_{MT} - \pi_{ik}\right)
\end{aligned}
$$

where $i \in \{M, m\}$ and $k \in \{T, t\}$. Recall that $\breve{C}$ is the inverse of the marginal cost function. Therefore, the derivative of $\breve{C}$ at zero is equal to the inverse of the derivative of C at zero; and the latter is given by $C''(0)$. It follows that $\breve{C}'(0) = \phi_C$. The same argument implies that $\breve{D}'(0) = \phi_D$.

Finally, the result follows by application of Taylor's theorem. ■

Proof of Lemma 2: The dynamic model induces a Markov process with two states: in state 1 the market leader is also the technology leader; in state $_{Mt}$ different firms take market and technology leadership. Let μ be the steady-state probability of being in state 1. Let m_s be the probability of transition to state s, $s \in \{1, _{Mt}\}$. We then have

$$
\begin{aligned}
m_1 &= y_{mT}\left(1 - y_{Mt}\right)\left(1 - x_{Mt}\left(1 - x_{mT}\right)\right) + x_{Mt}\left(1 - x_{mT}\right)\left(1 - y_{mT}\left(1 - y_{Mt}\right)\right) \\
m_0 &= y_{mt}\left(1 - y_{MT}\right)\left(1 - x_{mt}\left(1 - x_{MT}\right)\right) + x_{mt}\left(1 - x_{MT}\right)\left(1 - y_{mt}\left(1 - y_{MT}\right)\right)
\end{aligned}
$$

The steady state probability of being in state 1 is then given by

$$
\mu = \frac{m_1}{m_0 + m_1}
$$

Note that $\widehat{m}_i = 0$. Therefore, $\widehat{\mu}$ results in an indeterminacy. Applying L'Hôpital's rule, we have

$$
\widehat{\mu} = \frac{\dot{m}_1}{\dot{m}_0 + \dot{m}_1} = \frac{\dot{y}_{mT} + \dot{x}_{Mt}}{\dot{y}_{mt} + \dot{x}_{mt} + \dot{y}_{mT} + \dot{x}_{Mt}} \tag{7}
$$

Substituting (1) into (2),

$$
\begin{aligned}
X &\equiv \mu\left(1 - \left(1 - x_{MT}\right)\left(1 - x_{mt}\right)\right) + (1-\mu)\left(1 - \left(1 - x_{Mt}\right)\left(1 - x_{mT}\right)\right) \\
Y &\equiv \mu\left(1 - \left(1 - y_{MT}\right)\left(1 - y_{mt}\right)\right) + (1-\mu)\left(1 - \left(1 - y_{Mt}\right)\left(1 - y_{mT}\right)\right)
\end{aligned} \tag{8}
$$

Differentiating (8) with respect to δ at $\delta = 0$,

$$
\begin{aligned}
\dot{X} &= \widehat{\mu}\, \dot{x}_{mt} + \left(1 - \widehat{\mu}\right)\, \dot{x}_{Mt} \\
\dot{Y} &= \widehat{\mu}\, \dot{y}_{mt} + \left(1 - \widehat{\mu}\right)\left(\dot{y}_{Mt} + \dot{y}_{mT}\right)
\end{aligned}
$$

Substituting (7) for $\widehat{\mu}$,

$$
\begin{aligned}
\dot{X} &= \frac{\left(\dot{y}_{mT} + \dot{x}_{Mt}\right)\, \dot{x}_{mt} + \left(\dot{y}_{mt} + \dot{x}_{mt}\right)\, \dot{x}_{Mt}}{\dot{y}_{mt} + \dot{x}_{mt} + \dot{y}_{mT} + \dot{x}_{Mt}} \\
\dot{Y} &= \frac{\left(\dot{y}_{mT} + \dot{x}_{Mt}\right)\, \dot{y}_{mt} + \left(\dot{y}_{mt} + \dot{x}_{mt}\right)\left(\dot{y}_{Mt} + \dot{y}_{mT}\right)}{\dot{y}_{mt} + \dot{x}_{mt} + \dot{y}_{mT} + \dot{x}_{Mt}}
\end{aligned} \tag{9}
$$

Since $\widehat{X} = \widehat{Y} = 0$, the result follows. ■

Proof of Proposition 1: Consider first the case of incremental innovation. From (9), $\phi_D = 0$ implies that, in the neighborhood of $\delta = 0$,

$$\dot{X} = \frac{2\,\dot{x}_{Mt}\,\dot{x}_{mt}}{\dot{x}_{mt} + \dot{x}_{Mt}}$$

Since, at $\delta = 0$, $x_{ik} = X = 0$, in the neighborhood of $\delta = 0$

$$X \approx \frac{2\,x_{Mt}\,x_{mt}}{x_{mt} + x_{Mt}}$$

It follows that $dX\,/\,d\alpha < 0$ if and only if

$$\left(\frac{dx_{Mt}}{d\alpha}\,x_{mt} + x_{Mt}\,\frac{dx_{mt}}{d\alpha}\right)(x_{mt} + x_{Mt}) - \left(\frac{dx_{Mt}}{d\alpha} + \frac{dx_{mt}}{d\alpha}\right) x_{Mt}\,x_{mt} < 0$$

or simply

$$(x_{mt})^2\,\frac{dx_{Mt}}{d\alpha} + (x_{Mt})^2\,\frac{dx_{mt}}{d\alpha} < 0$$

Substituting the values from Lemma 1 the result's expression is obtained. Finally, for $\phi_D > 0$, the result follows by continuity.

Consider now the case of drastic innovation. From (9), $\phi_D \to \infty$ implies that

$$\dot{Y} = \frac{\dot{y}_{mt}\,\left(2\,\dot{y}_{mT} + \dot{y}_{Mt}\right)}{\dot{y}_{mt} + \dot{y}_{mT}}$$

Since, at $\delta = 0$, $y_{ik} = X = 0$, in the neighborhood of $\delta = 0$

$$Y \approx \frac{y_{mt}\,\left(2\,y_{mT} + y_{Mt}\right)}{y_{mt} + y_{mT}}$$

It follows that $dY\,/\,d\alpha > 0$ if and only if

$$\left(\frac{dy_{mt}}{d\alpha}\,\left(2\,y_{mT} + y_{Mt}\right) + y_{mt}\,\left(2\,\frac{dy_{mT}}{d\alpha} + \frac{dy_{Mt}}{d\alpha}\right)\right)(y_{mt} + y_{mT}) - \left(\frac{dy_{mt}}{d\alpha} + \frac{dy_{mT}}{d\alpha}\right) y_{mt}\,\left(2\,y_{mT} + y_{Mt}\right) < 0$$

or simply

$$\frac{dy_{mt}}{d\alpha}\,\left(2\,y_{mt} + y_{Mt}\right) + \frac{dy_{mT}}{d\alpha}\,\left(2\,y_{mt} - y_{Mt}\right) + \frac{dy_{Mt}}{d\alpha}\,(y_{mt} + y_{mT}) > 0$$

which in turn follows from Lemma 1 and Part (b) of Assumption 3. ■

Proof of Lemma 3: Technology transfer takes place at state $_{Mt}$ and only at that state. Specifically, if firms find themselves in state $_{Mt}$ then upon successful negotiations they move to state 1, where continuation values are given by (v_{MT}, v_{mt}). Let p be the price paid by the market-dominant firm for the superior technology. The dominant firm's gain from technology transfer is then given by $(v_{MT} - p) - v_{Mt}$, whereas the rival firm's gain from technology transfer is given by $(v_{mt} + p) - v_{mT}$. It follows that the Nash bargaining transfer price solves

$$\max_p \ (v_{MT} - p - v_{Mt})\,(v_{mt} + p - v_{mT})$$

which implies

$$\widehat{p} = \tfrac{1}{2}(v_{MT} - v_{Mt} + v_{mT} - v_{mt})$$

In equilibrium, firm mT sells the technology for $\widehat{p}$ and becomes a technology laggard.

Let u_{ik} denote the interim value before negotiations take place. Then we have

$$\begin{aligned} u_{mT} &= v_{mt} + \widehat{p} = \tfrac{1}{2}\,(v_{MT} - v_{Mt} + v_{mT} + v_{mt}) \\ u_{Mt} &= v_{MT} - \widehat{p} = \tfrac{1}{2}\,(v_{MT} + v_{Mt} - v_{mT} + v_{mt}) \end{aligned} \tag{10}$$

whereas $u_{ik} = v_{ik}$ for all other cases. Value functions are now given by

$$\begin{aligned} v_{MT} &= \pi_{MT} - C(x_{MT}) - D(y_{MT}) + \delta\, y_{MT}\, v_{MT} + \delta\,\big(1 - y_{MT}\big)\, y_{mt}\, v_{mt} \\ &\quad + \delta\,\big(1 - y_{mt}\big)\big(1 - y_{MT}\big)\,\Big(x_{mt}\,\big(1 - x_{MT}\big)\, u_{Mt} + \Big(1 - x_{mt}\,\big(1 - x_{MT}\big)\Big)\, v_{MT}\Big) \\ v_{Mt} &= \pi_{Mt} - C(x_{Mt}) - D(y_{Mt}) + \delta\, y_{Mt}\, v_{MT} + \delta\,\big(1 - y_{Mt}\big)\, y_{mT}\, v_{mt} \\ &\quad + \delta\,\big(1 - y_{mT}\big)\big(1 - y_{Mt}\big)\,\Big(x_{Mt}\,\big(1 - x_{mT}\big)\, v_{MT} + \Big(1 - x_{Mt}\,\big(1 - x_{mT}\big)\Big)\, u_{Mt}\Big) \\ v_{mT} &= \pi_{mT} - C(x_{mT}) - D(y_{mT}) + \delta\, y_{Mt}\, v_{mt} + \delta\,\big(1 - y_{Mt}\big)\, y_{mT}\, v_{MT} \\ &\quad + \delta\,\big(1 - y_{Mt}\big)\big(1 - y_{mT}\big)\,\Big(x_{Mt}\,\big(1 - x_{mT}\big)\, v_{mt} + \Big(1 - x_{Mt}\,\big(1 - x_{mT}\big)\Big)\, u_{mT}\Big) \\ v_{mt} &= \pi_{mt} - C(x_{mt}) - D(y_{mt}) + \delta\, y_{MT}\, v_{mt} + \delta\,\big(1 - y_{MT}\big)\, y_{mt}\, v_{MT} \\ &\quad + \delta\,\big(1 - y_{MT}\big)\big(1 - y_{mt}\big)\,\Big(x_{mt}\,\big(1 - x_{MT}\big)\, u_{mT} + \Big(1 - x_{mt}\,\big(1 - x_{MT}\big)\Big)\, v_{mt}\Big) \end{aligned} \tag{11}$$

The first-order conditions for optimal x_{ik} and y_{ik} are isomorphic to (5) and (6), with the difference that we have u_{ik} on the right-hand side instead of v_{ik}.

$$\begin{aligned} x_{MT} &= \breve{C}\Big(\delta\,\big(1 - y_{mt}\big)\big(1 - y_{MT}\big)\ x_{mt}\,(v_{MT} - u_{Mt})\Big) \\ x_{Mt} &= \breve{C}\Big(\delta\,\big(1 - y_{mt}\big)\big(1 - y_{MT}\big)\ \big(1 - x_{mT}\big)\,(v_{MT} - u_{Mt})\Big) \\ x_{mT} &= \breve{C}\Big(\delta\,\big(1 - y_{mt}\big)\big(1 - y_{MT}\big)\ x_{Mt}\,(u_{mT} - v_{mt})\Big) \\ x_{mt} &= \breve{C}\Big(\delta\,\big(1 - y_{mt}\big)\big(1 - y_{MT}\big)\ \big(1 - x_{MT}\big)\,(u_{mT} - v_{mt})\Big) \end{aligned} \tag{12}$$

$$\begin{aligned} y_{MT} &= \breve{D}\Big(\delta\, y_{mt}\,(v_{MT} - v_{mt}) + \delta\,\big(1 - y_{mt}\big)\ x_{mt}\,\big(1 - x_{MT}\big)\,(v_{MT} - u_{Mt})\Big) \\ y_{Mt} &= \breve{D}\Big(\delta\, y_{mT}\,(v_{MT} - v_{mt}) + \delta\,\big(1 - y_{mT}\big)\,\Big(1 - x_{Mt}\,\big(1 - x_{mT}\big)\Big)\,(v_{MT} - u_{Mt})\Big) \\ y_{mT} &= \breve{D}\Big(\delta\,\big(1 - y_{Mt}\big)\,\Big(v_{MT} - x_{Mt}\,\big(1 - x_{mT}\big)\, v_{mt} - \Big(1 - x_{Mt}\,\big(1 - x_{mT}\big)\Big)\, u_{mT}\Big)\Big) \\ y_{mt} &= \breve{D}\Big(\delta\,\big(1 - y_{Mt}\big)\,\Big(v_{MT} - x_{mt}\,\big(1 - x_{MT}\big)\, u_{mT} - \Big(1 - x_{mt}\,\big(1 - x_{MT}\big)\Big)\, v_{mt}\Big)\Big) \end{aligned} \tag{13}$$

Substituting 0 for δ in (11), we get

$$\widehat{v}_{ik} = \pi_{ik}$$

Substituting 0 for δ in (10), we get

$$\begin{aligned} \widehat{u}_{mT} &= \tfrac{1}{2}\left(\pi_{MT} - \pi_{Mt} + \pi_{mT} + \pi_{mt}\right) \\ \widehat{u}_{Mt} &= \tfrac{1}{2}\left(\pi_{MT} + \pi_{Mt} - \pi_{mT} + \pi_{mt}\right) \end{aligned}$$

whereas $\widehat{u}_{ik} = \widehat{v}_{ik} = \pi_{ik}$ for all other cases. Regarding the values of x_{ik}, y_{ik}, we have

$$\begin{aligned} \widehat{x}_{ik} &= 0, \\ \widehat{y}_{ik} &= 0 \\ \dot{x}_i^t &= \breve{C}'(0)\left(\widehat{u}_i^T - \widehat{u}_i^t\right) \\ \dot{y}_i^t &= \breve{D}'(0)\left(\widehat{u}_{MT} - \widehat{u}_i^t\right) \end{aligned}$$

or simply

$$\begin{aligned} \dot{x}_{ik} &= \tfrac{1}{2}\,\phi_C\left(\pi_{MT} + \pi_{mT} - \pi_M^k - \pi_m^k\right) \\ \dot{y}_{ik} &= \tfrac{1}{2}\,\phi_D\left(\pi_{MT} - \pi_{mt} - \pi_{ik} + \pi_j^\ell\right) \end{aligned}$$

where $i, j \in \{M, m\}$, $k, \ell \in \{T, t\}$, $j \neq i$ and $\ell \neq k$. The result follows. ■

Proof of Proposition 2: In equilibrium, whenever the dominant firm is the technology laggard it acquires the rival's technology. As a result, at the beginning of each period the dominant firm is the technology leader, either as a result of its innovation effort or as a result of technology acquisition. It follows that $\mu = 1$.

Consider first the implications for incremental innovation. Since $\mu = 1$ under technology transfer, (1) and (2)

$$\dot{X} = \dot{X}_1 = \dot{x}_{mt} + \dot{x}_{MT}$$

Lemma 3 implies

$$\dot{X} = \dot{x}_{it} = \tfrac{1}{2}\,\phi_C\left(\pi_{MT} + \pi_{mT} - \pi_{Mt} - \pi_{mt}\right) \tag{14}$$

By contrast, absent technology tranfer,

$$\dot{X} = \mu\,\phi_C\left(\pi_{mT} - \pi_{mt}\right) + (1-\mu)\,\phi_C\left(\pi_{MT} - \pi_{Mt}\right) \tag{15}$$

From (7)

$$\widehat{\mu} = \frac{\dot{x}_{Mt}}{\dot{x}_{mt} + \dot{x}_{Mt}} \approx \frac{\pi_{MT} - \pi_{Mt}}{\pi_{MT} - \pi_{Mt} + \pi_{mT} - \pi_{mt}} \tag{16}$$

Part (c) of Assumption 3 implies that $\pi_{MT} - \pi_{Mt} > \pi_{mT} - \pi_{mt}$. From (16), it follows that $\widehat{\mu} > \frac{1}{2}$. Note that the right-hand sides of (14) and (15) are convex combinations of $\pi_{MT} - \pi_{Mt}$ and $\pi_{mT} - \pi_{mt}$; but the latter places a greater weight on the lower term. Finally, given we have strict inequalities, the result follows by continuity.

Consider now the case of drastic innovation. Since $\mu = 1$ under technology transfer, (1) and (2) imply

$$\dot{Y} = \dot{Y}_1 = \dot{y}_{mt} + \dot{y}_{MT}$$

Lemma 3 then implies that

$$\dot{Y} = \phi_D (\pi_{MT} - \pi_{mt})$$

Lemma 1 implies that, under no technology transfer,

$$\begin{aligned} \dot{Y}_1 &= \dot{y}_{mt} + \dot{y}_{MT} = \phi_D (\pi_{MT} - \pi_{mt}) \\ \dot{Y}_{Mt} &= \dot{y}_{mT} + \dot{y}_{Mt} = \phi_D (\pi_{MT} - \pi_{mT}) + \phi_D (\pi_{MT} - \pi_{Mt}) \end{aligned}$$

It follows that the value of Y under technology transfer is lower than under no technology transfer if and only if

$$(\pi_{MT} - \pi_{mT}) + (\pi_{MT} - \pi_{Mt}) > (\pi_{MT} - \pi_{mt})$$

which is equivalent to

$$\pi_{MT} - \pi_{Mt} > \pi_{mT} - \pi_{mt}$$

which follows from Assumption 3 (c). Finally, the result follows by continuity. ■

Proof of Proposition 3: Consider first the case of incremental innovation. From Lemma 3,

$$X \approx \tfrac{1}{2}\, \phi_C \left(\pi_{MT} - \pi_{Mt} + \pi_{mT} - \pi_{mt}\right)$$

The result then follows from parts (c) and (d) of Assumption 3.

Consider now the case of drastic innovation. From the proof of Proposition 2, if the limit as $\phi_D \to \infty$,

$$\dot{Y} = \frac{\dot{y}_{mt}\left(2\,\dot{y}_{mT} + \dot{y}_{Mt}\right)}{\dot{y}_{mt} + \dot{y}_{mT}}$$

Since, at $\delta = 0$, $y_{ik} = Y = 0$, in the neighborhood of $\delta = 0$

$$Y \approx \frac{y_{mt}\left(2\,y_{mT} + y_{Mt}\right)}{y_{mt} + y_{mT}}$$

It follows that, if ϕ_D is sufficiently high and δ is sufficiently low, then $dY/d\alpha > 0$ if and only if

$$\left(\frac{dy_{mt}}{d\alpha}\left(2\,y_{mT} + y_{Mt}\right) + y_{mt}\left(2\,\frac{dy_{mT}}{d\alpha} + \frac{dy_{Mt}}{d\alpha}\right)\right)(y_{mt} + y_{mT}) - \left(\frac{dy_{mt}}{d\alpha} + \frac{dy_{mT}}{d\alpha}\right) y_{mt}\left(2\,y_{mT} + y_{Mt}\right) < 0$$

or simply

$$\frac{dy_{mt}}{d\alpha}\left(2\,y_{mt} + y_{Mt}\right) + \frac{dy_{mT}}{d\alpha}\left(2\,y_{mt} - y_{Mt}\right) + \frac{dy_{Mt}}{d\alpha}\left(y_{mt} + y_{mT}\right) > 0$$

From Lemma 2 and Assumption 3, the terms in brackets, as well as the partial derivatives, are all positive. Finally, the result follows by continuity. ■

References

Aghion, P., Bloom, N., Blundell, R., Griffith, R., and Howitt, P. "Competition and Innovation: An Inverted-U Relationship." *The Quarterly Journal of Economics*, Vol. 120 (2005), pp. 701–728.

Aghion, P., Harris, C., and Vickers, J. "Competition and Growth with Step-by-step Innovation: An Example." *European Economic Review*, Vol. 41 (1997), pp. 771–782.

Arora, A., Fosfuri, A., and Gambardella, A. "Markets for Technology and their Implications for Corporate Strategy." *Industrial and Corporate Change*, Vol. 10 (2001), pp. 419–451.

Arrow, K.J. "Economic Welfare and the Allocation of Resources for Invention." In *The Rate and Direction of Inventive Activity: Economic and Social Factors*, 609–626. National Bureau of Economic Research, Inc (1962) .

Budd, C., Harris, C., and Vickers, J. "A Model of the Evolution of Duopoly: Does the Asymmetry between Firms Tend to Increase or Decrease?" *Review of Economic Studies*, Vol. 60 (1993), pp. 543–73.

Galasso, A. and Schankerman, M. "Patents and Cumulative Innovation: Causal Evidence from the Courts." *Quarterly Journal of Economics*, Vol. 130 (2015), pp. 317–369.

Gans, J.S., Hsu, D.H., and Stern, S. "When Does Start-Up Innovation Spur the Gale of Creative Destruction?" *RAND Journal of Economics*, Vol. 33 (2002), pp. 571–586.

Gans, J.S. and Stern, S. "Incumbency and R&D incentives: Licensing the Gale of Creative Destruction." *Journal of Economics & Management Strategy*, Vol. 9 (2000), pp. 485–511.

—. "The Product Market and the Market for Ideas: Commercialization Strategies for Technology Entrepreneurs." *Research Policy*, Vol. 32 (2003), pp. 333–350.

Gilbert, R.J. and Newbery, D.M.G. "Preemptive Patenting and the Persistence of Monopoly." *American Economic Review*, Vol. 72 (1982), pp. 514–26.

Goettler, R.L. and Gordon, B. "Does AMD Spur Intel to Innovate More?" *Journal of Political Economy*, Vol. 119 (2011), pp. 1141–1200.

Green, J.R. and Scotchmer, S. "On the Division of Profit in Sequential Innovation." *RAND Journal of Economics*, Vol. 26 (1995), pp. 20–33.

Hermalin, B.E. "Unobserved investment, endogenous quality, and trade." *RAND Journal of Economics*, Vol. 44 (2013), pp. 33–55.

Phillips, G.M. and Zhdanov, A. "R&D and the Incentives from Merger and Acquisition Activity." *Review of Financial Studies*, Vol. 26 (2013), pp. 34–78.

Rasmusen, E. "Entry for Buyout." *Journal of Industrial Economics*, Vol. 36 (1988), pp. 281–99.

Reinganum, J.F. "Uncertain Innovation and the Persistence of Monopoly." *American Economic Review*, Vol. 73 (1983), pp. 741–48.

Scotchmer, S. "Standing on the Shoulders of Giants: Cumulative Research and the Patent Law." *Journal of Economic Perspectives*, Vol. 5 (1991), pp. 29–41.

—. "Protecting Early Innovators: Should Second-Generation Products Be Patentable?" *RAND Journal of Economics*, Vol. 27 (1996), pp. 322–331.

Segal, I. and Whinston, M.D. "Antitrust in Innovative Industries." *American Economic Review*, Vol. 97 (2007), pp. 1703–1730.

Spulber, D. "How Do Competitive Pressures Affect Incentives to Innovate When There Is a Market for Inventions?" *Journal of Political Economy*, Vol. 121 (2013).