Standing on the Shoulders of Dwarfs: 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 "dwarfs"); (b) technology transfer by acquisition; and (c) the distinction between radical innovation (compete for the market) and incremental innovation (compete within the market). I provide conditions such that (a) greater asymmetry between giant and dwarfs decreases incremental innovation but increases radical innovation; and (b) allowing for technology transfer increases incremental innovation but decreases radical innovation.

These results have several policy implications, including: (a) a soft antitrust policy toward dominant firms leads to an increase in radical innovation but a decrease in incremental innovation; (b) a merger policy that restricts the acquisition of fringe firms by dominant firms leads to lower incremental innovation rates and higher radical innovation rates; (c) the effect of IP protection on radical innovation is ambiguous: on the one hand, it increases the prize effect of innovation; on the other hand, it improves the working of markets for technology, which in turn reduces the rate of radical 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 dominant firm 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, a number of positive and normative questions arise. For example:

- How does the antitrust treatment of dominant firms — in cases such as *US vs Microsoft* or *DG Comp vs Intel* influence the rates of incremental and radical innovation?
- Markets for technology (MFT) vary significantly across industries (Arora et al., 2001; Gans and Stern, 2003). How do better MFT influence incremental and radical innovation?
- Is a tougher merger policy good for incremental innovation? Radical innovation?

In this paper, I tackle these and related 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.

■ **Model summary.** 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). For example, Powerpoint has greater market value in the hands of Microsoft than in the hands of a smaller firm such as Forethought (its original developer); or: Instagram creates more value when integrated in Facebook than as an independent startup. I refer to the dominant firm's rival as the fringe firm.

I assume radical 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*. In other words, incremental innovation corresponds to competition *within* the market, whereas radical innovation corresponds to competition *for* the market.[1]

1. Referring to high-tech industries, Evans and Schmalensee (2002) argue that "firms engage in dynamic competition *for the market* — usually through research and development (R&D) to develop the 'killer' product, service, or feature that will confer market leadership." I would classify this as radical innovation, although I would not consider it to be the only type of innovation strategy.

I consider an infinite-period innovation game: in each period, firms (a) receive product market payoffs according to their current industry and technology state; (b) simultaneously choose (at a cost) probabilities of incremental and radical 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).[2] I solve the model with a combination of analytical methods (low values of the discount factor) and numerical methods (all values of the discount factor).[3]

In order to consider the possibility of technology transfer, I change the timing of the game by assuming that, in each period, after the outcomes from innovation efforts are observed, firms have the ability to negotiate a transfer of technology: by paying a transfer price p, the technology laggard becomes a technology leader (and vice-versa).[4]

My analysis consists in determining the equilibrium of the dynamic innovation game and studying its comparative statics with respect to: (a) the degree of market dominance: a greater value of the parameter α implies a greater market profit for the dominant firm, all else constant constant; and a lower market profit for the fringe firm; (b) the efficiency of markets for technology: I consider two extreme possibilities, no technology transfer or efficient technology transfer.

■ **Main results summary.** The analysis leads to three main results. First, absent technology transfer, an increase in the degree of firm dominance leads to a decrease in incremental innovation. This is perhaps the most complex result as it conflates several effects of opposite sign: As a dominant firm becomes more dominant, its incentives to innovate increase, especially when its technology falls behind its rival's. The same increase in firm dominance decreases the fringe firm's incentive to catch up when its technology falls behind the dominant firm's. In absolute terms, the encouragement effect is greater than the discouragement effect. However, along the steady state the fringe firm is the technology laggard more often than the dominant firm, which in turn implies that, overall, the effect of firm dominance is to decrease incremental innovation.[5] I call this the *shadow of Google* effect. It is related to a common complain in several high-tech industries:

> 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."[6]

In my model's context and absent technology transfer, "Google getting in" means imitation by a dominant firm. Even if the dominant firm does not reach the same level as the technology leader (and fringe firm), its complementary assets allow it to eat considerably into the fringe firm's market share:

2. As in Aghion et al. (1997) and Segal and Whinston (2007), the technology state 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).
3. A similar approach is followed in Budd et al. (1993) and Cabral (2011).
4. I assume efficient bargaining, which implies technology transfer takes place when the dominant firm is a technology laggard.
5. This is one of several instances where a dynamic model provides answers qualitatively different from, or unattainable by, a static game.
6. *The New York Times*, May 2, 2006.

> If imitation is the sincerest form of flattery, then Google must love streaming music rivals like Pandora, Spotify and Rdio. That's because Google Play Music All Access looks pretty similar to them.[7]

Things change considerably when we consider markets for technology. My second result is that technology transfer leads to an increase in incremental innovation. Suppose the fringe firm succeeds in incremental innovation. Such innovation is more valuable if in the hands of the dominant firm. Accordingly, Nash bargaining implies that the technology is transferred to the dominant firm at a price that splits the gains from an agreement. This in turn implies that the fringe firm partly internalizes the dominant firm's value from incremental innovation, leading to an increase in total gain from innovation. I call this the *innovation for buyout* effect.

> Now that Google has reportedly agreed to buy Israeli crowd-powered navigation app Waze for $1.3 billion, many other "Silicon Wadi" startups are daring to dream big.[8]

Against this positive effect of technology transfer, my third result states that technology transfer leads to an decrease in radical innovation. Under technology transfer, the dominant firm is always the technology leader, either as a result of its own innovation efforts or by acquiring a technology leader. As a result, the incentives for a dominant firm to engage in radical innovation are lower than under no technology transfer. In fact, in a world where the dominant firm can become technology leader by acquisition, radical innovation would result in a complete replacement of its current position: dominant firm and technology leader.

Moreover, when there is technology transfer the fringe firm expects that, by succeeding in *incremental* innovation, it will attain a higher payoff than when there is no technology transfer. In other words, technology transfer increases the "opportunity cost" of radical innovation for the technology lagging fringe firm.

All in all, technology transfer leads to a *complacency effect* that cuts into incremental innovation by both the dominant and the fringe firm.

■ **Implications.** These results have several policy implications. First, regarding the issue of antitrust on innovation (Segal and Whinston, 2007), it's important to distinguish radical innovation (competition for the market) from incremental innovation (competition within the market): a soft antitrust policy toward dominant firms leads to an increase in radical innovation (partly Microsoft's point in the *US v Microsoft* case) but also leads to a decrease in incremental innovation (partly the government's point in the same case).

Second, my results have implications for the relation between two public policy instruments: the treatment of dominant firms and the protection of intellectual property (IP). I show that a lenient treatment of dominant firms or strong patents are substitute instruments to increase the radical innovation rate. Intuitively, both increase the "prize" of being the dominant firm (and, most often, the technology leader as well). However, a *tough* treatment of dominant firms or strong patents are substitute instruments to increase the incremental innovation rate. In other words, tough market competition is good for incremental innovation but bad for radical innovation.

7. http://www.wallstreetdaily.com/2013/05/16/google-streaming-music-service/, visited June 8, 2017.
8. https://www.fastcompany.com/3012685/6-israeli-startups-to-watch-as-google-reportedly-buys-waze-for-13-billion, visited June 8, 2017.

Third, two qualifications must be made to the previous statement when considering the moderating effect of markets for technology. First, when it comes to the acquisition of fringe firms by dominant firms, a tougher treatment of dominant firms (a more restrictive merger policy) leads to *lower* incremental innovation rates and *higher* radical innovation rates (the opposite of the effect of policy regarding abuse of dominant position). Second, the effect of IP protection on radical innovation is ambiguous: on the one hand, it increases the prize effect of innovation; on the other hand, it improves the working of markets for technology, which in turn reduces the rate of radical innovation.

Finally, with respect to the issue of persistence of leadership, I argue that 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 (Arrow, 1962; Reinganum, 1983) implies that technology laggards are more likely to innovate; but the efficiency effect (Gilbert and Newbery, 1982) implies that dominant firms are more likely to persist as technology leaders.

■ **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. Two important differences of my paper with respect to theirs are that (a) I consider the possibility of firm acquisition, namely acquisition of a technology leader by a market leader; and (b) I distinguish between incremental and radical innovation.

Segal and Whinston (2007) assume that "if the potential entrant innovates, it receives a patent, enters, competes with the incumbent in the present period, and then becomes the incumbent in the next period, while the previous incumbent then becomes the potential entrant." As such, their innovation combines incremental and radical innovation. I believe that much of the confusion in the policy debate regarding dominant firms and innovation incentives stems from conflating incremental and radical innovation into one single dimension. One of the important results I develop refers precisely to the trade-off between incremental and radical 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 (see also Gans et al., 2002). 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 deals 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.[9]

The above papers share some of the features of the framework I develop in this paper. 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.[10]

■ **Roadmap.** 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. In Section 5 I discuss some implications of the results. Section 6 includes a series of extensions of the basic framework, whereas Section 7 concludes the paper.

2. Model and assumptions

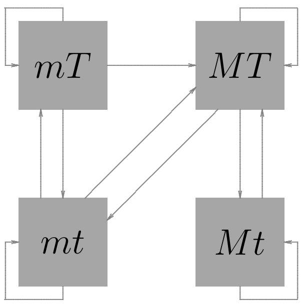
Consider an industry with two firms and an infinite series of periods $t = 1, 2, \ldots$. In each period, there is a market dominant firm, which I denote by the subscript M; and a fringe firm, which I denote by the subscript m. As well, there is a technology leader, which I denote by the subscript T; and a technology laggard, which I denote by the subscript 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

9. 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.

10. There are some additional related papers, including Goettler and Gordon (2011), Hermalin (2013), Rasmusen (1988), to which I will refer later in the paper.

Figure 1
State space and state transitions



their state: π_{ik}, where $i \in \{M, m\}$ and $k \in \{T, t\}$.[11] Next firms simultaneously spend $C(x_{ik})$ and $D(y_{ik})$ to achieve incremental innovation probability x_{ik} and radical 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 radical innovation, then it becomes a dominant firm *and* a technology leader; if both firms are simultaneously successful in radical innovation, then the previously dominant firm remains dominant.
- If a firm is successful in incremental innovation (and no firm is successful in radical innovation), then such firm becomes a technology leader; if both firms are simultaneously successful in incremental innovation, then the previous technology leader remains a technology leader.

Intuitively, incremental innovation is akin to moving up a given ladder, whereas radical innovation corresponds to moving to a completely new ladder — and taking a leading position on that new ladder.

My assumption that there are only two states regarding technology position — leader or laggard — echoes the assumption in Aghion et al. (1997) and Segal and Whinston (2007) that IP protection is limited and imitation is possible. This implies that, at all times, the technology laggard is able to remain at a given distance from the 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

$$\mathbb{P}(mT \mid mt) = \left(1 - y_{MT}\right)\left(1 - y_{mt}\right)\left(1 - x_{MT}\right) x_{mt} \tag{1}$$

As a second example, the probability of remaining in state MT requires that either (a) the market dominant firm has a radical innovation; or (b) no firm has a radical innovation

11. 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.

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

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

As a third example, the probability of moving from state MT to state mt is is the probability that the laggard radically 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 in hand, I can derive the firms' value functions v_{ik} recursively. For example,

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

The Appendix includes a complete set of value functions. 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 MT

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

where $\breve{C}$ and $\breve{D}$ are the inverse of C' and D', respectively; and C' and D' are the first derivative functions 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 radical innovation rates at each state are given by

$$\begin{aligned} X_1 &= 1 - \big(1 - x_{mt}\big)\,\big(1 - x_{MT}\big) \\ X_0 &= 1 - \big(1 - x_{mT}\big)\,\big(1 - x_{Mt}\big) \\ Y_1 &= 1 - \big(1 - y_{mt}\big)\,\big(1 - y_{MT}\big) \\ Y_0 &= 1 - \big(1 - y_{mT}\big)\,\big(1 - y_{Mt}\big) \end{aligned} \tag{2}$$

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

Let μ be the steady-state probability of being in state 1. Then the steady-state innovation rates are given by

$$\begin{aligned} X &\equiv \mu\, X_1 + (1 - \mu)\, X_0 \\ Y &\equiv \mu\, Y_1 + (1 - \mu)\, Y_0 \end{aligned} \tag{3}$$

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

■ **Solution strategy and functional-form assumptions.** 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 $\delta = 0$. By solving for the unique equilibrium when $\delta = 0$ and showing 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.[12] As I will show, much of the "action" taking place for $\delta \gg 0$ is already present when $\delta \approx 0$; that is, the distance between $\delta = 0$ and $\delta \approx 0$ is "greater" than the distance between $\delta \approx 0$ and $\delta \gg 0$, in terms of qualitative results (see Budd et al., 1993; Cabral, 2011).

In an effort to make the results as general as possible, the analytical results place relatively few restrictions on functional forms. By contrast, the numerical computations are based on specific functional forms. Regarding product market functions, the numerical computations are based on the following product market model. There exists a continuum of consumers (normalized to a measure 1), each of whom buys one unit from one of the two sellers. Specifically, each consumer receives net utility u_{ik} from purchasing from a firm with market position i ($i = M, m$) and technology position k ($k = T, t$), which is given as follows:

$$u_{ik} = \alpha_i + \lambda_k - p_{ik} + \zeta_{ik} \tag{4}$$

where α_i denotes the extent of firm ik's market leadership, λ_k the extent of its technology leadership, p_{ik} is firm ik's price, and ζ_{ik} is the consumer's utility shock from buying firm ik's product. Specifically, $\alpha_i = \alpha$ if firm ik is the dominant firm (that is, $i = M$), $\alpha_i = 0$ otherwise.; and similarly, $\lambda_k = \lambda$ if firm ik is the technology leader, $\lambda_k = 0$ otherwise.

Suppose ζ_{ik} is sufficiently large that the market is covered, that is, the outside option is always dominated by one of the sellers. Given that, I work with $\xi_{ik} \equiv \zeta_{ik} - \zeta_{j\ell}$, the consumer's relative preference for firm ik ($j \in \{M, m\}$; $\ell \in \{T, t\}$; $j \neq i$; $\ell \neq k$). I further assume ξ_{ik} is distributed according to a normal $N(0, \sigma^2)$ distribution; and, with no further loss of generality, assume $\sigma^2 = 1$. It can be shown (Cabral and Riordan, 1994) that, under these assumptions,

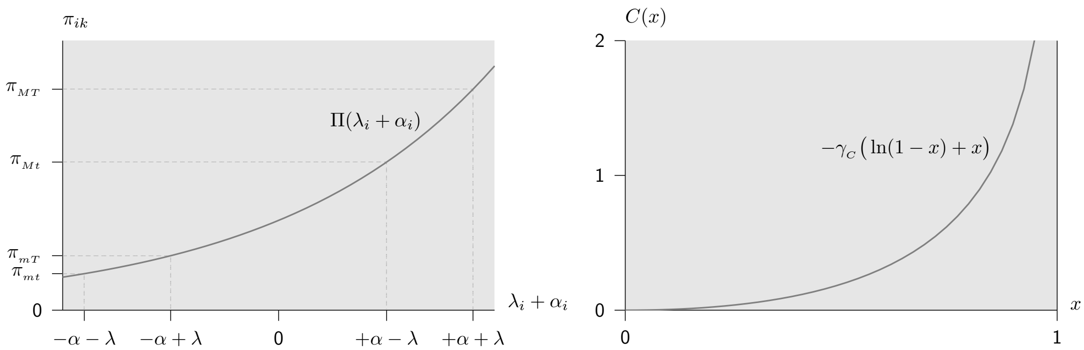
$$\pi_{ik} = \frac{\big(1 - F(\lambda_i + \alpha_i)\big)^2}{f(\lambda_i + \alpha_i)} \equiv \Pi(\lambda_i + \alpha_i)$$

where F and f are the cdf and pdf of ξ, respectively. The left panel of Figure 2 illustrates this result. The highest market profit corresponds to being a dominant firm and a technology leader, the lowest from being fringe firm and a technology laggard. The ordering of the intermediate values, π_{Mt} and π_{mT}, depends on the relative value of α and λ. Notice that Π is convex.[13] This implies that the gain from being a technology leader, $\pi_{iT} - \pi_{it}$, is greater for the dominant firm ($i = M$) than for the fringe firm ($i = m$). Moreover, as α

12. As often is the case with this type of models, I have no general analytical uniqueness result (only in the neighborhood of $\delta = 0$). I try multiple starting values and convergence algorithms and always obtain the same equilibrium.

13. In addition to the Normal, this feature is true for various symmetric distributions of ξ I considered, including the uniform and t distributions.

Figure 2
Profit levels, where α measures market dominance and λ technology dominance ($\alpha > \lambda > 0$); and cost of incremental innovation ($\gamma_C = 1$)



increases, the benefit of technology leadership increases for the dominant firm and decreases for the fringe firm; and, in absolute value, the increase is greater than the decrease. These properties of the profit function, which echo the joint-profit effect in Gilbert and Newbery (1982), play an important role in a series of results.

For the purpose of my analytical results, I make the following assumptions:

Assumption 1. $\pi_{iT} > \pi_{it}$

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

Assumption 2. *(a)* $\pi_{ik} = \pi_{jk}$ *if* $\alpha = 0$*; (b)* π_{Mk} *is increasing in* α *and* π_{mk} *is decreasing in* α*;*[14] *(c)* $(\pi_{MT} - \pi_{Mt})$ *is increasing in* α *and* $(\pi_{mT} - \pi_{mt})$ *is decreasing in* α*; (d)* $\big|\, d\left(\pi_{MT} - \pi_{Mt}\right)/d\alpha \,\big| \;>\; \big|\, d\left(\pi_{mT} - \pi_{mt}\right)/d\alpha \,\big|$

Parts (a) and (b) indicate that α measures market dominance: conditional on technology state, the greater α is the greater the dominant firm's profit and the lower then fringe firm's; and if $\alpha = 0$ then we get symmetry (dominant and fringe firms earn the same profit, conditional on their technology state). Parts (c) and (d) state that the value of technology leadership is greater and increases at a faster rate for the dominant firm.

Regarding the cost functions, and for the purpose of numerical computation, I assume the following:

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

These functional forms have the desirable properties that marginal cost is zero at zero innovation probability and infinity at probability-one innovation probability. For the purpose of my analytical results, I impose a series of Inada-like conditions that generalize the above boundary features:

14. This is similar to Segal and Whinston (2007), who consider $\pi_I(\alpha)$ and $\pi_E(\alpha)$ — the incumbent's and entrant's profit functions, respectively — as a function of α, which in their case is a measure of antitrust activity.

Assumption 3. *(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 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 radical innovation, respectively. Consider for example ϕ_C. By part (c) of Assumption 3, 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.

To conclude, I note that not all assumptions are necessary for all of the analytical results in the next two sections. Moreover, the functional forms considered above 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; Cabral, 2011).

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 $\mathbb{O}(\delta^2)$.

In words, Lemma 1 states that, in the neighborhood of $\delta = 0$, the equilibrium incremental innovation race is approximately proportional to the difference between a firm's current profit and the profit it would receive if it were a technology leader. The constant of proportionality is given by ϕ_C, which reflects the curvature of the innovation cost structure: the greater ϕ_C, the less convex the cost curve, that is, the less the innovation cost increases as the probability of innovation increases. A similar reasoning applies for radical innovation.

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 an equally valuable leadership position. A similar reasoning applies to radical innovation.

By solving for the stationary state of the Markov process induced by firm innovation rates I am able to go from equilibrium firm strategies to the overall probabilities of incremental and radical 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 $\mathbb{O}(\delta^2)$.

Unlike Lemma 1, which follows directly from a Taylor expansion around $\delta = 0$, the proof of Lemma 2 requires some additional work: in order to compute the steady-state innovation rate, we need to solve for the equilibrium Markov transition probabilities, and these probabilities are a function of the equilibrium levels of innovation effort.

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

$$-\frac{d(\pi_{MT} - \pi_{Mt})\,/\,d\alpha}{d(\pi_{mT} - \pi_{mt})\,/\,d\alpha} < \frac{(\pi_{MT} - \pi_{Mt})^2}{(\pi_{mT} - \pi_{mt})^2} \tag{5}$$

By Assumption 2 (d), the left-hand side is greater than 1. Condition (5) places an upper bound on the value of the left-hand side. By Assumption 2 (c) and (d), the right-hand side is strictly greater than 1; therefore, Condition (5), together with Assumption 2, define a non-empty set of profit functions.

In words, Assumption 2 states that the profit function is convex: as the degree of dominance increases, the dominant firm's profit increases by more than the fringe firm's decreases. Condition (5) places an upper bound on this convexity property. It is relevant for the incremental innovation result that follows.[15] 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* $\overline{\phi}_D$ *such that, if* $\phi_D < \overline{\phi}_D$, *then the steady-state incremental-innovation rate,* X, *is decreasing in the degree of market dominance* α *if and only if (5) holds.*
- *There exist a* $\overline{\overline{\phi}}_D$ *such that, if* $\phi_D > \overline{\overline{\phi}}_D$, *then the steady-state radical-innovation rate,* Y, *is increasing in the degree of market dominance* α.

A high value of ϕ_D means that the conditions for radical innovation are relatively attractive when compared with incremental innovation. In other words, if the value of ϕ_D is very high then we would expect high equilibrium values of y_{ik} and most of the innovation performance to result from radical innovation. The condition $\phi_D > \overline{\phi}_D$ may thus be interpreted as meaning that radical innovation is relatively important (with respect to incremental innovation). Proposition 1 may thus be rephrased as follows: if incremental innovation is relatively important, then an increase in firm dominance leads to a decrease in incremental innovation; and if radical innovation is relatively important, then an increase in firm dominance leads to an increase in radical innovation.

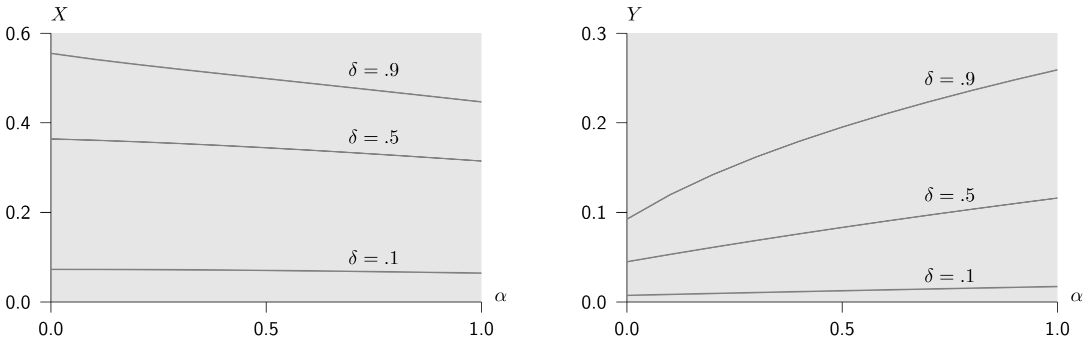
Note that Proposition 1, an analytical result, is only valid in the neighborhood of $\delta = 0$. Figure 3 plots the value of X and Y as a function of α for higher values of δ. The numerical results confirm the signs predicted by Proposition 1.[16]

The intuition for the first part of Proposition 1 (incremental innovation) proceeds in three steps. First, if δ is small then the replacement effect is very strong for technology

15. There is a certain similarity with respect to condition (1) in Segal and Whinston (2007).

16. Unless otherwise stated, my base-case simulations assume $\lambda = 1$, $\phi_C = 1$, $\phi_D = .1$. I performed multiple computations with different parameter values; the qualitative results are the same.

Figure 3
Firm dominance and innovation



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.

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 (dominant firm has a lot to gain) outweighs the discouragement effect of market dominance (fringe firm has little to gain).

Third, along the steady-state the probability that the dominant firm 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 dominant firm is the technology leader is proportional to the dominant firm'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. Proposition 1 shows that, for low values of δ, the "extensive margin" effect dominates, so that the innovation probability declines. Numerically, I show that the same is true for higher values of δ.

Still another way to understand the effect of firm dominance on innovation rates is to differentiate the first equation in (3) with respect to α:

$$\begin{array}{cccc} \dfrac{dX}{d\alpha} = & \underbrace{\mu\,\dfrac{dX_1}{d\alpha} + (1-\mu)\,\dfrac{dX_0}{d\alpha}} & + \dfrac{d\mu}{d\alpha} & (X_1 - X_0) \\ < 0 & > 0 & > 0 & < 0 \end{array}$$

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 4
Encouragement and discouragement effects ($\delta = .1$)

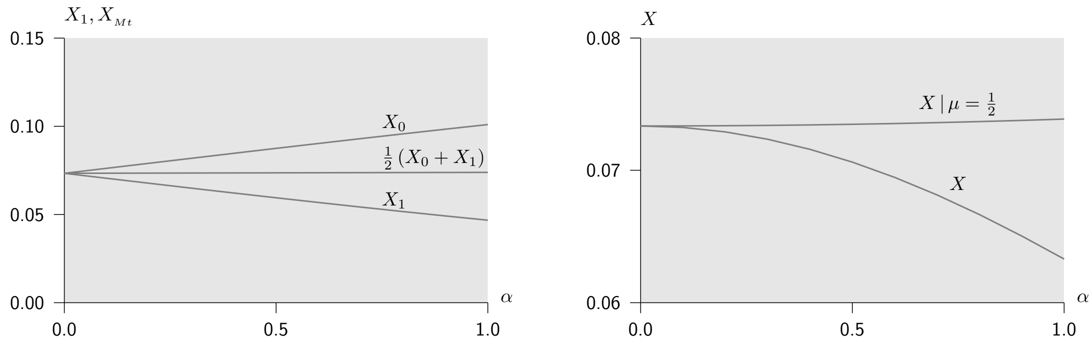


Figure 4 restates the same ideas in a different way. The left panel shows how X_0 and X_1 vary with respect to α. As mentioned earlier, an increase in firm dominance (and increase in α) implies an encouragement effect (higher effort when the dominant firm is a technology laggard, which corresponds to an increase in X_0); but it also implies a discouragement effect (lower effort when the fringe firm is a technology laggard, which corresponds to a decrease in X_1). If we give both effects equal weight, we get a positive (if small) average, as shown on the left panel.[17]

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 4 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 (because the encouragement effect dominates the discouragement effect). 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

17. Specifically, the encouragement effect is greater, in absolute value, then the discouragement effect; if $\delta = 0$, then they exactly cancel out.

from an agreement are equally split among the two parties).[18] 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 (fringe firm is technology leader) but not in state 1 (dominant firm is technology leader).

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

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

where

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

I now follow a process similar to the no-transfer case: I expand the value functions in the neighborhood of $\delta = 0$ so as to obtain the approximate value of the firm's equilibrium innovation rates:

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

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

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

Lemma 3 shows the implications of split bargaining: transfer of incentives. Consider the case of incremental innovation. Absent technology transfer, we have

$$\begin{aligned} x_{Mt} &\approx \phi_C\,(\pi_{MT} - \pi_{Mt}) \\ x_{mt} &\approx \phi_C\,(\pi_{mT} - \pi_{mt}) \end{aligned}$$

18. 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. Spulber (2012), in turn, looks at the interaction of tacit knowledge with the trade-off between entrepreneurship and technology transfer. He shows that major inventions tend to result in entrepreneurship, minor inventions in technology transfer. This is consistent with my assumption that technology innovation only applies to incremental innovation.

By contrast, when technology transfer is possible, we have

$$x_{it} \approx \tfrac{1}{2}\,\phi_C\,(\pi_{MT} - \pi_{Mt}) + \tfrac{1}{2}\,\phi_C\,(\pi_{mT} - \pi_{mt})$$

that is, one half of the gain for a dominant firm plus one half of the gain for a fringe firm, a value which is independent of i. A fringe firm which is a technology laggard anticipates that, upon successful innovation, its technology will be sold to the dominant firm. This explains why $\pi_{MT} - \pi_{Mt}$ is part of firm mt's expected benefit from innovation, and why it enters the expression determining the firm's innovation rate. Similarly, a dominant firm who is currently a technology laggard anticipates that, if it successfully innovates, it will *not* have to acquire a technology leader. The greater $\pi_{mT} - \pi_{mt}$ is, the greater the price M will need to pay for m's technology. Therefore, the greater greater $\pi_{mT} - \pi_{mt}$ is, the greater M's incentive to innovate.

What does this all imply in terms of the overall incremental innovation rate? As before, answering these questions requires solving for the dynamic model's stationary state.

■ **Innovation for buyout.** The next result derives implications in terms of the steady-state rate of incremental 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.*

If technology transfer is not an option, then for a low value of the discount factor the incentives for incremental innovation are proportional to $\pi_{MT} - \pi_{Mt}$ (if the dominant firm is the technology laggard) or $\pi_{mT} - \pi_{mt}$ (if the fringe firm is the technology laggard). Since μ is the steady-state probability that the dominant firm is also the technology leader, it follows hat the steady-state incremental-innovation rate is approximately proportional to

$$(1-\mu)\,(\pi_{MT} - \pi_{Mt}) + \mu\,(\pi_{mT} - \pi_{mt}) \tag{6}$$

Now suppose that technology transfer is possible. Whenever the dominant firm is the technology laggard, technology transfer takes place. As a result, at the moment of deciding on incremental innovation, the dominant firm is also the technology leader. As seen before, the first-order innovation effort comes from the technology laggard, in this case the fringe firm. Efficient bargaining implies that firms split the gain from technology transfer: in equilibrium, a \$1 increase in firm i's value is shared with firm j. This in turn implies that effectively, the fringe firm's gain from incremental innovation is approximately proportional to

$$\tfrac{1}{2}\,(\pi_{MT} - \pi_{Mt}) + \tfrac{1}{2}\,(\pi_{mT} - \pi_{mt}) \tag{7}$$

This convex combination of $\pi_{MT} - \pi_{Mt}$ and $\pi_{mT} - \pi_{mt}$ is higher than (6), since it places greater weight on the higher term (Assumption 2 implies that $\pi_{MT} - \pi_{Mt} > \pi_{mT} - \pi_{mt}$).

To put it differently, technology transfer implies that the fringe firm partly internalizes the dominant firm's gain from incremental innovation; and the dominant firm's gain from incremental innovation is greater than the fringe firm's gain; and the fringe firm's incentive is what matters the most along the steady state.

Technology transfer turns the fringe firm's strategy into one of innovation for buyout. 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.

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, Proposition 2 is consistent with their theoretical and empirical results. In fact, mergers and acquisitions can be a form of technology tranfer.

■ **The complacency effect.** My next result shows that, contrary to incremental innovation, technology transfer has a negative effect on radical innovation.

Proposition 3. *There exists $\overline{\delta}$ such that, if $\delta < \overline{\delta}$, then allowing for technology transfer implies a decrease in the steady-state radical innovation rate, Y.*

The intuition for this result is two-fold. Consider first the dominant firm. Under technology transfer, the dominant firm is always the technology leader, either as a result of its own innovation efforts or by acquiring a technology leader. This implies that the incentives for a dominant firm to engage in radical innovation are lower than under no technology transfer. In fact, in a world where the dominant firm can become technology leader by acquisition, radical innovation would result in a complete replacement of its current position: dominant firm and technology leader. In other words, technology transfer increases the likelihood of an Arrow replacement effect (Arrow, 1962; Reinganum, 1983) on the dominant firm's incentives.

Consider now the fringe firm. The crucial point is that the radical innovation prize, which is approximately given by the difference $v_{MT} - v_{mt}$, becomes lower under technology transfer: although both v_{MT} and v_{mt} increase when technology transfer is possible, v_{mt} increases by more than v_{MT}. Intuitively, when there is technology transfer, the fringe firm expects that, by succeeding in *incremental* innovation, it will attain a higher payoff than when there is no technology transfer. For this reason, technology transfer increases the "opportunity cost" of radical innovation for the technology lagging fringe firm.

In other words, technology transfer shifts the steady-state weight to the state in which the dominant firm has the lowest incentives for radical innovation; and it reduces the fringe's firm radical innovation prize precisely because of the positive effect of technology transfer on incremental innovation. Together, I call this effect of technology transfer the *complacency effect*.

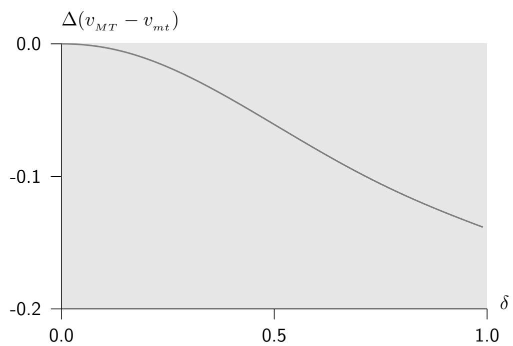
I should note that the second effect considered above (effect on firm mt) is of second order when $\delta = 0$, but becomes first order when $\delta \gg 0$. However, since it points in the same direction as the first effect, Proposition 3 is valid for both low and high values of δ. Figure 5 plots $\Delta(v_{MT} - v_{mt})$, the difference $v_{MT} - v_{mt}$ with and without technology transfer:

$$\Delta(v_{MT} - v_{mt}) \equiv (v_{MT} - v_{mt})\big|_{\text{tech transfer}} - (v_{MT} - v_{mt})\big|_{\text{no tech transfer}}$$

As can be seen, for $\delta = 0$ this difference is zero and its derivative with respect to δ is also equal to zero. However, as δ increases, it becomes higher, the difference becomes strictly negative.

Together, Propositions 2 and 3 show that there is a trade-off between incremental innovation and radical innovation when it comes to the effect of technology transfer. As we

Figure 5
Effect of technology transfer on gain from radical innovation ($\delta = .1$). Δ denotes the difference between the cases with technology transfer and without technology transfer; $v_{MT} - v_{mt}$ denotes the value difference between a market and technology leader and a market and technology laggard



saw in the previous section, this is also true with respect to market dominance. The signs, however, are reversed: under no technology transfer, market dominance is good for radical innovation but bad for incremental innovation; whereas technology transfer is good for incremental innovation but bad for radical innovation.

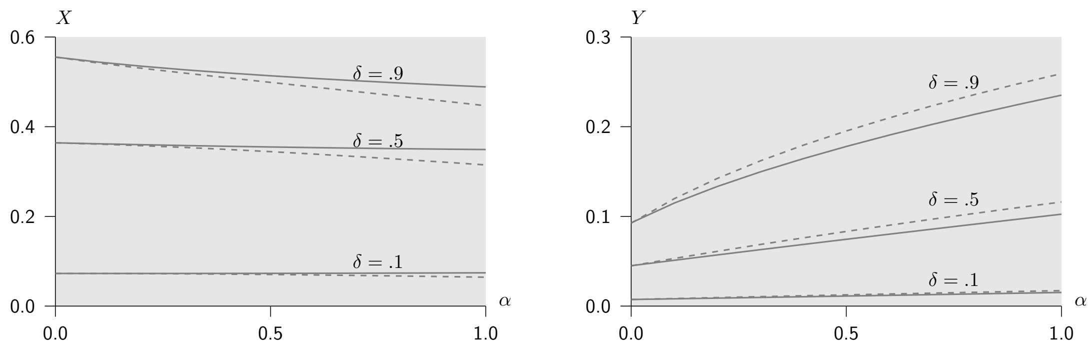
■ **Firm dominance and innovation.** I finally turn to the issue of market dominance and innovation incentives when there is technology transfer. Intuitively, there are two effects at play: on the one hand, an increase in market dominance increases the relative bargaining power of firm M with respect to firm m (which will frequently be the innovator); on the other hand, an increase in market dominance increases firm M's valuation for the innovation, which should help firm m sell its innovation. Which effect dominantes?

Proposition 4. *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 radical innovation rate, Y, increases as the degree of firm dominance α increases.*

Figure 6 illustrates both Propositions 2, 3 and 4. The dashed lines correspond to the equilibrium without technology transfer, whereas the solid lines correspond to the case with technology transfer. Although Propositions 2 and 3 are 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 places the dominant firm as a technology leader (either by its own innovation effort or by acquisition). This reduces that firm's incentives for radical innovation, an effect I call the "complacency" effect.

Figure 6
Firm dominance and innovation: Steady-state incremental innovation rate (X) and radical innovation rate (Y) without technology transfer (dotted line) and with technology transfer (solid line) as a function of the degree of market dominance (α) for different values of the discount factor (δ)



Proposition 4 states that, with technology transfer (solid lines in Figure 6) and when $\delta \approx 0$, both incremental as radical innovation rates increase as the degree of industry dominance (α) increases. The two panels in Figure 6 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 the incentives for incremental innovation.[19]

5. Discussion

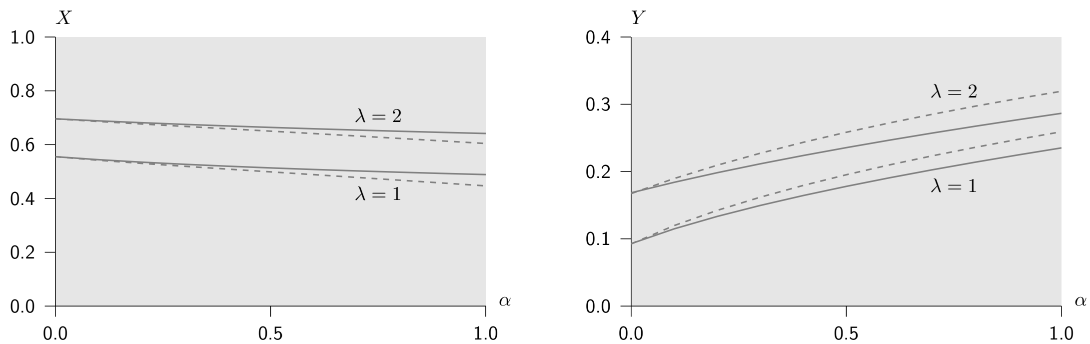
In this section, I discuss some implications of the results presented in the previous sections.

■ **Antitrust and innovation.** A central focus of the paper is on the effects of antitrust on innovation. Introducing this topic, Segal and Whinston (2007) argue that, in the Microsoft case,

> Microsoft argued that while as a technological leader it may possess a good deal of static market power, this is merely the fuel for stimulating dynamic R&D competition, a process that it argued works well in the software industry. Antitrust intervention would run the risk of reducing the rate of innovation and welfare. The government argued, instead, that Microsoft's practices prevented entry of new firms and products, and therefore both raised prices and retarded innovation.

19. Of all the results presented in the paper, this is the only one where numerical simulations for higher values of δ lead to qualitative different results than the analytical result for $\delta \approx 0$. But even in this case the two effects underlying the numerical result can be traced back to component effects which can be derived analytically.

Figure 7
Firm dominance and innovation: Steady-state incremental innovation rate (X) and radical innovation rate (Y) without technology transfer (dotted line) and with technology transfer (solid line) as a function of the degree of market dominance (α) for different values of the technology lag (λ). (Discount factor $\delta = .9$ in all cases.)



My results are consistent with Microsoft's view — if we consider "dynamic R&D competition" from the radical innovation point of view. In fact, as Propositions 1 and 4 show, an increase in α (lenient antitrust policies) leads to an increase in radical innovation. My results are also consistent with the government's view that Microsoft's dominance (hight α) dampens incremental innovation, especially by rival firms. This is then one of the main points that follow from my analysis: it makes a big difference whether one refers to incremental innovation (competition within the market) or to radical innovation (competition for the market).

■ **IP policy and antitrust policy instruments.** At the risk of oversimplifying the policy debate, one may say that competition policy (or antitrust) is primarily based on instruments such as horizontal agreements and treatment of dominant firms; whereas innovation policy is primarily based on intellectual property (IP) protection instruments. This is unfortunate, for the various instruments are clearly related: IP protection has market power implications and the treatment of dominant firms has implications for innovation.

In the context of my model, the treatment of dominant firms is parameterized by α: a higher value of α corresponds to a system that is more lenient towards dominant firms.[20] Although the paper does not focus on IP policy, there is a natural parameter (used in the numerical computations) that reflects IP policy: λ. Recall that λ measures the benefit from technology leadership; a stronger IP protection policy therefore corresponds to a higher value of λ.

Figure 7 shows the steady-state rates of incremental and radical innovation as a function of α for two different levels of λ: $\lambda = 1$ (the base case I have considered throughout the paper) and $\lambda = 2$. As can be seen, a higher value of λ leads to higher rates of incremental innovation. This is not surprising: it corresponds to the well-known "prize effect" of patents: the promise of rents leads firms to invest more. The effect on the incremental innovation rate is also a reflection of this prize effect: in equilibrium, the dominant firm is also the technology leader in most periods along the steady state.

20. There may be other factors that influence the value of α, but here I focus on public policy toward dominant firms.

Other than this uniform increase in innovation rates, an increase in λ does not change the basic trade-offs regarding the value of α or the availability of markets for technology. Given this, we may say that a lenient treatment of dominant firms (high α) or strong patents (high λ) are substitute instruments to increase the radical innovation rate. However, a *tough* treatment of dominant firms (low α) or strong patents (high λ) are substitute instruments to increase the incremental innovation rate. In other words, tough market competition is good for incremental innovation but bad for radical innovation.

Another area where antitrust policy and innovation policy instruments overlap is mergers and acquisitions. My results suggest that, in industries with dominant/fringe firms, an improvement in markets for technology leads to an increase in incremental innovation and a decrease in radical innovation. There are various factors that contribute to better working markets for technology: one is the ability of dominant firms to acquire fringe firms; a second one is a well-defined property rights system (Gans et al., 2002).

This suggests some qualifications to my previous statements regarding antitrust and innovation policy. A tough treatment of dominant firms, as measured by α, leads to higher incremental innovation rates and lower radical innovation rates. Examples of policy-induced changes in α include policies with respect to abuse of dominant position (as in the *US v Microsoft* or *DG Comp v Intel* cases). By contrast, when it comes to the treatment of dominant firms' acquisition of fringe firms my results suggest that a tough treatment of dominant firms leads to *lower* incremental innovation and *higher* radical innovation rates.

With respect to innovation policy, stronger IP protection unambiguously contributes to higher incremental innovation rates, for two reasons: first, stronger patents increase the prize from successful innovation; and second, stronger IP rights contribute to better markets for technology, which in turn increases the incentives for incremental innovation. However, the effect on radical innovation is ambiguous: on the one hand, the prize effect leads to higher innovation rates; on the other hand, better markets for technology make firms more complacent with the current dominant/fringe state, that is, less prone to engage in radical 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 and of second order, whereas the technology laggard's is close to zero but of first 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 dominant firm *or* by the fringe firm (e.g., sold at an auction), then the dominant would have more to lose from not acquiring that innovation than the fringe firm. As such, we would expect that the dominant firm 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 dominant firms are more likely to persist as technology leaders.

■ **Welfare analysis.** The analysis in the paper is focused on innovation rates; there is no claim regarding the optimality of firm dominance in terms of consumer or total welfare. However, in industries where innovation plays an important role in determining welfare one would expect the above results to be of first-order importance.

A second point regarding welfare is the relation between incremental and radical innovation. I showed two instances of a trade-off between the two types of innovation. First, under no technology transfer, an increase in firm dominance leads to a decrease in incremental innovation but an increase in radical innovation. Second, allowing for technology transfer leads to an increase in incremental innovation but a decrease in radical innovation.

The above suggest two lines of follow-up research: first, a calibrated model where incremental and radical innovation rates contribute to an overall innovation rate. This would allow us to understand the effect of market dominance and technology transfer on innovation, especially when there is a trade-off between incremental and radical innovation. Second, a demand model with more structure so as to estimate the welfare effects of innovation (the fact that innovation rates increase does not necessarily imply that welfare increases).

6. Robustness and extensions

Throughout Sections 2–4, I made a series of simplifying modeling assumptions. In this section, I consider a series of possible extensions of my basic framework.

■ **Number of fringe firms.** For simplicity, I assumed the existence of one dominant firm and one fringe firm. Considering the structure of many high-tech industries, it would be more realistic to consider $n > 1$ fringe firms. In an anonymous equilibrium (only a firm's state matters, not its identity), we would still have four states, as in Figure 1. Transition probabilities would of course be computed differently. For example, instead of (1) we would have

$$\mathbb{P}(mT \,|\, mt) = \big(1 - y_{MT}\big)\big(1 - y_{mt}\big)^n \, \big(1 - x_{MT}\big)\, x_{mt} \sum_{i=0}^{n-1} \left(\frac{1}{1+i}\right) x_{mt}^i \, (1 - x_{mt})^{n-1-i}$$

where I assume that, if more than one fringe firm succeeds in incremental innovation, then each becomes technology leader with equal probability. Although the math becomes considerably more complicated, my analysis so far suggests that the qualitative nature of the results remains valid.

■ **State transition rules.** For simplicity, I assumed very specific state-transition rules. Specifically, when there are two competing innovations, I assumed that the current leader remains a leader (either a dominant firm or a technology leader). Alternatively, I could have assumed that there is a probability ρ that the laggard leapfrogs the leader. Although the math becomes more complex, the basic qualitative results remain essentially the same.

■ **Bargaining solution.** Much of Google's revenues correspond to advertising. Google's advertising technology was obtained in two important steps: first, it acquired Applied Semantics to get Adsense. Second, it attempted to acquire Idealab, but the target would not sell. As a result, Google imitated their IP, eventually settling an IP dispute in court.

These episodes remind us that information asymmetries and other market imperfections are part and parcel of the real world. In this sense, my assumption of efficient, split-surplus bargaining is rather extreme. However, my results regarding technology transfer are based on strict inequalities. For this reason, they are not knife-edged and would survive a series of perturbations. Specifically, I could assume that technology transfer negotiations fail with some probability. I could also assume a generalized Nash solution whereby the dominant firm receives a share β of the surplus.

There is however one caveat. Galasso and Schankerman (2015) show that bargaining frictions in technology transfer are greater when the asymmetry between buyer and seller is greater. My result that, under technology transfer, incremental innovation rates increase with greater firm dominance could easily be reversed if the dominant firm's share of surplus were significantly increasing in the degree of asymmetry: a bigger Google increases the surplus from technology transfer, but it also increases Google's share of the deal. The net effect on the fringe firm could then go either way.

7. 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 dwarfs." In this paper, I considered two versions of this phenomenon: imitation and acquisition. The first version takes place when small firms invent only to see their ideas copied by "giants" who leverage their market power to effectively appropriate the value generated by "dwarfs." The second version takes place when small inventors ("dwarfs") are gobbled up by dominant firms ("giants").[21]

I proposed a framework that addresses several issues in the imitation/acquisition game played between dominant and fringe firms. In addition to markets for technology, the framework explicitly distinguishes between incremental and radical innovation.

I derived a series of analytical results. As an illustration of these results, we might say that a bigger Google increases Google's incentive to improve GooglePlay but decreases Pandora's incentive to improve its service; and along the steady-state the latter effect dominates. Moreover, better markets for technology increase the frequency of new apps like Waze but decrease the frequency of new Googles.

These results have several policy implications, including

- A soft antitrust policy toward dominant firms leads to an increase in radical innovation

21. 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).

but a decrease in incremental innovation.

- A merger policy that restricts the acquisition of fringe firms by dominant firms leads to lower incremental innovation rates and higher radical innovation rates
- The effect of IP protection on radical innovation is ambiguous: on the one hand, it increases the prize effect of innovation; on the other hand, it improves the working of markets for technology, which in turn reduces the rate of radical innovation.

Appendix

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

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

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

$$
\begin{aligned}
x_{MT} &= \breve{C}\Big(\delta\,(1-y_{mt})(1-y_{MT})\; x_{mt}\,(v_{MT}-v_{Mt})\Big) \\
x_{Mt} &= \breve{C}\Big(\delta\,(1-y_{mt})(1-y_{MT})\;(1-x_{mT})\,(v_{MT}-v_{Mt})\Big) \\
x_{mT} &= \breve{C}\Big(\delta\,(1-y_{mt})(1-y_{MT})\; x_{Mt}\,(v_{mT}-v_{mt})\Big) \\
x_{mt} &= \breve{C}\Big(\delta\,(1-y_{mt})(1-y_{MT})\;(1-x_{MT})\,(v_{mT}-v_{mt})\Big)
\end{aligned}
\tag{8}
$$

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

$$
\begin{aligned}
y_{MT} &= \breve{D}\Big(\delta\, y_{mt}\,(v_{MT}-v_{mt}) + \delta\,(1-y_{mt})\; x_{mt}\,(1-x_{MT})\,(v_{MT}-v_{Mt})\Big) \\
y_{Mt} &= \breve{D}\bigg(\delta\, y_{mT}\,(v_{MT}-v_{mt}) + \delta\,(1-y_{mT})\Big(1-x_{Mt}\,(1-x_{mT})\Big)(v_{MT}-v_{Mt})\bigg) \\
y_{mT} &= \breve{D}\bigg(\delta\,(1-y_{Mt})\Big(v_{MT} - x_{Mt}\,(1-x_{mT})\, v_{mt} - \Big(1-x_{Mt}\,(1-x_{mT})\Big)\, v_{mT}\Big)\bigg) \\
y_{mt} &= \breve{D}\bigg(\delta\,(1-y_{Mt})\Big(v_{MT} - x_{mt}\,(1-x_{MT})\, v_{mT} - \Big(1-x_{mt}\,(1-x_{MT})\Big)\, v_{mt}\Big)\bigg)
\end{aligned}
\tag{9}
$$

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

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

$$
\begin{aligned}
\dot{v}_{ik} &= \pi_{ik} \\
\dot{x}_{ik} &= \breve{C}'(0)\left(\widehat{v}_{iT} - \widehat{v}_{ik}\right) = \phi_C\left(\pi_{iT} - \pi_{ik}\right) \\
\dot{y}_{ik} &= \breve{D}'(0)\left(\widehat{v}_{MT} - \widehat{v}_{ik}\right) = \phi_D\left(\pi_{MT} - \pi_{ik}\right)
\end{aligned}
$$

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 dominant firm 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

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

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

$$
\widehat{\mu} = \frac{\dot{m}_1}{\dot{m}_0 + \dot{m}_1} = \frac{\dot{y}_{mT} + \dot{x}_{Mt}}{\dot{y}_{mt} + \dot{x}_{mt} + \dot{y}_{mT} + \dot{x}_{Mt}} \tag{10}
$$

Substituting (2) into (3),

$$
\begin{aligned}
X &\equiv \mu\Big(1 - \left(1 - x_{MT}\right)\left(1 - x_{mt}\right)\Big) + (1 - \mu)\Big(1 - \left(1 - x_{Mt}\right)\left(1 - x_{mT}\right)\Big) \\
Y &\equiv \mu\Big(1 - \left(1 - y_{MT}\right)\left(1 - y_{mt}\right)\Big) + (1 - \mu)\Big(1 - \left(1 - y_{Mt}\right)\left(1 - y_{mT}\right)\Big)
\end{aligned} \tag{11}
$$

Define, for a generic variable z,

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

Differentiating (11) 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 (10) for $\widehat{\mu}$,

$$
\begin{aligned}
\dot{X} &= \frac{\left(\dot{y}_{mT} + \dot{x}_{Mt}\right)\,\dot{x}_{mt} + \left(\dot{y}_{mt} + \dot{x}_{mt}\right)\,\dot{x}_{Mt}}{\dot{y}_{mt} + \dot{x}_{mt} + \dot{y}_{mT} + \dot{x}_{Mt}} \\
\dot{Y} &= \frac{\left(\dot{y}_{mT} + \dot{x}_{Mt}\right)\,\dot{y}_{mt} + \left(\dot{y}_{mt} + \dot{x}_{mt}\right)\left(\dot{y}_{Mt} + \dot{y}_{mT}\right)}{\dot{y}_{mt} + \dot{x}_{mt} + \dot{y}_{mT} + \dot{x}_{Mt}}
\end{aligned} \tag{12}
$$

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

Proof of Proposition 1: Define, for a generic variable z,

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

Consider first the case of incremental innovation. From (12), $\phi_D = 0$ 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 radical innovation. From (12), $\phi_D \to \infty$ 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 $\delta = 0$, $y_{ik} = 0$, 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 2. ■

Proof of Lemma 3: Technology transfer takes place at state 0 (dominant firm is technology laggard) and only at that state. Specifically, if firms find themselves in state 0, 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 fringe firm's gain from technology transfer is given by $(v_{mt} + p) - v_{mT}$. It follows that the Nash bargaining transfer price, $\widehat{p}$, 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

$$\begin{aligned} u_{mT} &= v_{mt} + \widehat{p} = \tfrac{1}{2}\,(v_{MT} - v_{Mt} + v_{mT} + v_{mt}) \\ u_{Mt} &= v_{MT} - \widehat{p} = \tfrac{1}{2}\,(v_{MT} + v_{Mt} - v_{mT} + v_{mt}) \end{aligned} \tag{13}$$

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

$$\begin{aligned} v_{MT} &= \pi_{MT} - C(x_{MT}) - D(y_{MT}) + \delta\, y_{MT}\, v_{MT} + \delta\,(1 - y_{MT})\, y_{mt}\, v_{mt} \\ &\qquad + \delta\,(1 - y_{mt})(1 - y_{MT}) \Big(x_{mt}\,(1 - x_{MT})\, u_{Mt} + \Big(1 - x_{mt}\,(1 - x_{MT})\Big)\, v_{MT} \Big) \\ v_{Mt} &= \pi_{Mt} - C(x_{Mt}) - D(y_{Mt}) + \delta\, y_{Mt}\, v_{MT} + \delta\,(1 - y_{Mt})\, y_{mT}\, v_{mt} \\ &\qquad + \delta\,(1 - y_{mT})(1 - y_{Mt}) \Big(x_{Mt}\,(1 - x_{mT})\, v_{MT} + \Big(1 - x_{Mt}\,(1 - x_{mT})\Big)\, u_{Mt} \Big) \\ v_{mT} &= \pi_{mT} - C(x_{mT}) - D(y_{mT}) + \delta\, y_{Mt}\, v_{mt} + \delta\,(1 - y_{Mt})\, y_{mT}\, v_{MT} \\ &\qquad + \delta\,(1 - y_{Mt})(1 - y_{mT}) \Big(x_{Mt}\,(1 - x_{mT})\, v_{mt} + \Big(1 - x_{Mt}\,(1 - x_{mT})\Big)\, u_{mT} \Big) \\ v_{mt} &= \pi_{mt} - C(x_{mt}) - D(y_{mt}) + \delta\, y_{MT}\, v_{mt} + \delta\,(1 - y_{MT})\, y_{mt}\, v_{MT} \\ &\qquad + \delta\,(1 - y_{MT})(1 - y_{mt}) \Big(x_{mt}\,(1 - x_{MT})\, u_{mT} + \Big(1 - x_{mt}\,(1 - x_{MT})\Big)\, v_{mt} \Big) \end{aligned} \tag{14}$$

The first-order conditions for optimal x_{ik} and y_{ik} are isomorphic to (8) and (9), with the difference that we have u_{ik} on the right-hand side instead of v_{ik}.

$$\begin{aligned} x_{MT} &= \breve{C}\Big(\delta\,(1 - y_{mt})(1 - y_{MT})\; x_{mt}\,(v_{MT} - u_{Mt})\Big) \\ x_{Mt} &= \breve{C}\Big(\delta\,(1 - y_{mt})(1 - y_{MT})\; (1 - x_{mT})\,(v_{MT} - u_{Mt})\Big) \\ x_{mT} &= \breve{C}\Big(\delta\,(1 - y_{mt})(1 - y_{MT})\; x_{Mt}\,(u_{mT} - v_{mt})\Big) \\ x_{mt} &= \breve{C}\Big(\delta\,(1 - y_{mt})(1 - y_{MT})\; (1 - x_{MT})\,(u_{mT} - v_{mt})\Big) \end{aligned} \tag{15}$$

$$\begin{aligned}
y_{MT} &= \breve{D}\Big(\delta\, y_{mt}\,(v_{MT}-v_{mt}) + \delta\,(1-y_{mt})\; x_{mt}\,(1-x_{MT})\,(v_{MT}-u_{Mt})\Big)\\
y_{Mt} &= \breve{D}\Big(\delta\, y_{mT}\,(v_{MT}-v_{mt}) + \delta\,(1-y_{mT})\,\big(1-x_{Mt}\,(1-x_{mT})\big)\,(v_{MT}-u_{Mt})\Big)\\
y_{mT} &= \breve{D}\Big(\delta\,(1-y_{Mt})\,\big(v_{MT}-x_{Mt}\,(1-x_{mT})\,v_{mt} - \big(1-x_{Mt}\,(1-x_{mT})\big)\,u_{mT}\big)\Big)\\
y_{mt} &= \breve{D}\Big(\delta\,(1-y_{Mt})\,\big(v_{MT}-x_{mt}\,(1-x_{MT})\,u_{mT} - \big(1-x_{mt}\,(1-x_{MT})\big)\,v_{mt}\big)\Big)
\end{aligned} \tag{16}$$

Define, for a generic variable z,

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

Substituting 0 for δ in (14), we get

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

Substituting 0 for δ in (13), we get

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

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

$$\begin{aligned}
\widehat{x}_{ik} &= 0,\\
\widehat{y}_{ik} &= 0\\
\dot{x}_{it} &= \breve{C}'(0)\,(\widehat{u}_{iT}-\widehat{u}_{it})\\
\dot{y}_{it} &= \breve{D}'(0)\,(\widehat{u}_{MT}-\widehat{u}_{it})
\end{aligned}$$

or simply

$$\begin{aligned}
\dot{x}_{ik} &= \tfrac{1}{2}\,\phi_C\,(\pi_{MT}+\pi_{mT}-\pi_{Mk}-\pi_{mk})\\
\dot{y}_{ik} &= \tfrac{1}{2}\,\phi_D\,\big(\pi_{MT}-\pi_{mt}-\pi_{ik}+\pi_{j\ell}\big)
\end{aligned}$$

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 $\mu = 1$. Given (2) and (3), this implies that the steady-state incremental innovation rate is given by

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

where we define, for a generic variable z,

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

Lemma 3 implies

$$\dot{X} = \dot{x}_{it} = \tfrac{1}{2}\,\phi_C\left(\pi_{MT} + \pi_{mT} - \pi_{Mt} - \pi_{mt}\right) \tag{17}$$

By contrast, absent technology tranfer,

$$\dot{X} = \mu\,\phi_C\left(\pi_{mT} - \pi_{mt}\right) + (1-\mu)\,\phi_C\left(\pi_{MT} - \pi_{Mt}\right) \tag{18}$$

From (10)

$$\widehat{\mu} = \frac{\dot{x}_{Mt}}{\dot{x}_{mt} + \dot{x}_{Mt}} \approx \frac{\pi_{MT} - \pi_{Mt}}{\pi_{MT} - \pi_{Mt} + \pi_{mT} - \pi_{mt}} \tag{19}$$

Part (c) of Assumption 2 implies that $\pi_{MT} - \pi_{Mt} > \pi_{mT} - \pi_{mt}$. From (19), it follows that $\widehat{\mu} > \frac{1}{2}$. Note that the right-hand sides of (17) and (18) 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. ■

Proof of Proposition 3: 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 $\mu = 1$. Given (2) and (3), this implies that the steady-state radical innovation rate is given by

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

Lemma 3 then implies that

$$\dot{Y} = \phi_D(\pi_{MT} - \pi_{mt}) \tag{20}$$

Lemma 1 implies that, under no technology transfer,

$$\begin{aligned} \dot{Y}_1 &= \dot{y}_{mt} + \dot{y}_{MT} = \phi_D(\pi_{MT} - \pi_{mt}) \\ \dot{Y}_0 &= \dot{y}_{mT} + \dot{y}_{Mt} = \phi_D(\pi_{MT} - \pi_{mT}) + \phi_D(\pi_{MT} - \pi_{Mt}) \end{aligned}$$

By the same argument that leads to (10), we conclude that $\dot{\mu} = 0$. This implies that $\dot{Y}$ under no technology transfer is greater than $\dot{Y}$ under technology transfer if and only if

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

which is equivalent to

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

which follows from Assumption 2 (c). Finally, the result follows by continuity. ■

Proof of Proposition 4: 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 2.

Consider now the case of radical innovation. From the proof of Proposition **??**, if the limit as $\phi_D \to \infty$,

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

where we define, for a generic variable z,

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

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 2, 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.

CABRAL, L. "Dynamic Price Competition with Network Effects." *Review of Economic Studies*, Vol. 78 (2011), pp. 83–111.

CABRAL, L. AND RIORDAN, M.H. "The Learning Curve, Market Dominance, and Predatory Pricing." *Econometrica*, Vol. 62 (1994), pp. 1115–40.

EVANS, D.S. AND SCHMALENSEE, R. "Some Economic Aspects of Antitrust Analysis in Dynamically Competitive Industries." In A Jaffe, J Lerner, S Stern (Eds), *Innovation Policy and the Economy*, Volume 2, Cambridge, MA: MIT Press (2002).

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.

Moser, P. and Wong, P. "Patents and Innovation: Evidence from Monsanto's Entry Into GMO Crops." Working paper (2016).

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.F. "Tacit Knowledge with Innovative Entrepreneurship." *International Journal of Industrial Organization*, Vol. 30 (2012), pp. 641 – 653.

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