Incumbency and R&D Incentives: Licensing the Gale of Creative Destruction

by

JOSHUA S. GANS *and* SCOTT STERN*

5 August, 1999

This paper analyzes the relationship between incumbency and innovative activity in the context of a model of technological competition in which *technologically* successful entrants are able to license their innovation to (or be acquired by) an incumbent. That such a sale ought to take place is natural since the post-innovation monopoly profits are greater than the sum of duopoly profits. The model integrates insights about the economic determinants of licensing fees (such as the size of knowledge spillovers or the sunk costs of product market entry) into the canonical model of technological competition under uncertainty. In so doing, we identify three key findings about how bargaining power during licensing negotiations impacts the incentives to engage in R&D. First, since an incumbent's threat to engage in imitative R&D during negotiations increases their bargaining power, our model identifies a purely strategic incentive for incumbents to develop an R&D capability. Second, incumbents research more intensively than entrants as long as (and only if) their "willingness-to-pay" for the innovation exceeds that of the entrant, a condition that depends critically on the expected size of the licensing fee. Third, when the expected licensing fee is sufficiently low, the incumbent considers entrant R&D a strategic substitute for in-house research. This stands in contrast to the prediction of strategic complementarity which arise in patent races where licensing is not allowed. *Journal of Economic Literature* Classification Numbers: Bargaining Theory (C78); Monopolization Strategies (L12); Vertical Integration (L22); R&D (O32).

Keywords: incumbent, entrant, research and development, innovation, bargaining, preemption, biotechnology, patent race.

* Melbourne Business School, University of Melbourne, and MIT Sloan School and NBER, respectively. We thank seminar participants at Stanford, Virginia, MIT, Queensland, and the Australian National University; and conference participants at the Australasian and North American Meetings of the Econometric Society and the Technology and the Organization of Industry Conference at the University of Urbino for helpful comments. Rebecca Henderson, Jorgen Pedersen, Rohan Pitchford, and Suzanne Scotchmer provided many useful suggestions. Financial assistance from a Special Initiatives Grant at the University of Melbourne is gratefully acknowledged. Responsibility for all views expressed remains our own. All correspondence to: Scott Stern, MIT Sloan School, E52-554, Cambridge, MA 02142; Fax: 617-253-2660; E-mail: sstern@mit.edu.

Incumbency and R&D Incentives: Licensing the Gale of Creative Destruction

5 August, 1999

This paper analyzes the relationship between incumbency and innovative activity in the context of a model of technological competition in which *technologically* successful entrants are able to license their innovation to (or be acquired by) an incumbent. That such a sale ought to take place is natural since the post-innovation monopoly profits are greater than the sum of duopoly profits. The model integrates insights about the economic determinants of licensing fees (such as the size of knowledge spillovers or the sunk costs of product market entry) into the canonical model of technological competition under uncertainty. In so doing, we identify three key findings about how bargaining power during licensing negotiations impacts the incentives to engage in R&D. First, since an incumbent's threat to engage in imitative R&D during negotiations increases their bargaining power, our model identifies a purely strategic incentive for incumbents to develop an R&D capability. Second, incumbents research more intensively than entrants as long as (and only if) their "willingness-to-pay" for the innovation exceeds that of the entrant, a condition that depends critically on the expected size of the licensing fee. Third, when the expected licensing fee is sufficiently low, the incumbent considers entrant R&D a strategic substitute for in-house research. This stands in contrast to the prediction of strategic complementarity which arise in patent races where licensing is not allowed. *Journal of Economic Literature* Classification Numbers: Bargaining Theory (C78); Monopolization Strategies (L12); Vertical Integration (L22); R&D (O32).

Keywords: incumbent, entrant, research and development, innovation, bargaining, preemption, biotechnology, patent race.

I. Introduction

Many research-oriented start-up firms earn their economic returns on innovative investments through cooperative arrangements with established, incumbent firms. This pattern of interaction between potential entrants and incumbents sharply contrasts with the (much-studied) Schumpeterian perspective – where innovation-driven entrants are the mechanism by which the "gale of creative destruction" is unleashed on entrenched monopolists. Motivated by the phenomena of cooperative arrangements between incumbent and entrants, the main goals of this paper are to evaluate (a) how the rents from innovation will be divided in an economic environment where cooperative agreements are feasible and (b) how the prospect of a "market for ideas" affects the R&D investment incentives of both incumbents and research-oriented start-ups.

Product market cooperation between incumbents and potential entrants occurs across industrial sectors and takes many forms, from simple technology licensing to production/marketing alliances to outright acquisition of the start-up by the incumbent. While the motivation for this paper is on the *general* choice of cooperation versus competition, our exposition focuses on technology licensing as the means by which cooperation is achieved. This allows us to evaluate how licensing fees – a useful representation of the potential entrant's rents from cooperation – are determined and impact R&D incentives.

Consider the biotechnology industry. While a small minority of biotechnology firms have integrated into the manufacture and distribution of new drugs, nearly all successful biotechnology firms have licensed their key innovations, joined downstream alliances, or been acquired outright by a more established firm (Orsenigo, 1991; Pisano and Mang, 1993; Lerner and Merges, 1998). In the early days of the biotechnology sector, the existence of strong intellectual property, along with the belief (at the time) that biotechnology firms could compete directly with established firms if licensing negotiations failed, resulted in relatively strong bargaining power for *technologically successful* start-up firms. For instance, in the “classic” patent race to develop synthetic insulin in the late 1970s, Genentech’s return from successful innovation did not come from product market entry but through a licensing agreement with Eli Lilly, the incumbent producer of cow and pig insulin. Both Genentech and Lilly purposefully sought out this contractual solution in order to avoid competing directly in the product market. Moreover, prior to Genentech’s success, Lilly directly invested in a competing research program at UC–SF (Hall, 1988; Barese and Brandenburger, 1992; Stern, 1995).

In contrast, in industries where intellectual property protection are weak and entry barriers are high, the distribution of bargaining power tends to be heavily weighted towards incumbent firms. For example, in addition to its substantial in-house software development, Microsoft systematically acquires independent software companies which produce software products complementary to the Windows operating system (but which are potential competitors with Microsoft applications). In most cases, Microsoft has tended to hold a great deal of strength in negotiations with such firms due to the inability of the start-up firm to (a) protect its intellectual property or (b) threaten to impose substantial competitive costs on Microsoft through participation in the product market (Cusumano and Selby, 1995).

Two issues stand out from these cases. First, bargaining power depends on the relative salience of two forces: the ability of the incumbent to expropriate the value of the start-up's innovation through imitation and the ability of the entrant to threaten the incumbent with competitive costs through product market entry. Second, in each case, licensing (or acquisition) follows a period of *simultaneous* R&D investment; research-oriented start-ups can only earn their return on innovation by successfully developing the technology prior to the incumbent. In such an environment, the prospect of licensing (and the distribution of bargaining power) will impact the incentives for both entrant and incumbent to engage in R&D in the first place.

This paper explores a model that incorporates both of these issues. As such, we build on the early insights of Salant (1984) and Katz and Shapiro (1987) that the availability of a licensing option can have an important impact on R&D competition.[1] We extend this work by incorporating insights from an emerging, more recent literature on the nature of bargaining over knowledge (Aghion and Tirole, 1994; Anton and Yao, 1995), which identifies how the competing threats of expropriation by the incumbent and product market entry by the start-up shape the division of the rents from innovation. While such work provides key insights into the determinants of the price of a technology license, this literature has not been reconnected to the more mature literature on strategic R&D investment; the contributions from this paper therefore arise from combining both perspectives into a single integrated model of technological competition and licensing.

[1] Several other authors have explored the impact of technology licensing on technological competition, including Gallini (1984), Gallini and Winter (1985), and Green and Scotchmer (1995). Reinganum (1989) provides a thorough review of these contributions and the R&D investment literature more generally.

Our analysis begins with the standard model of an innovation race under uncertainty (Reinganum, 1983). In contrast to the exogenously determined product market payoffs common to these models, we introduce a second-stage where, after successful entrant innovation, bargaining between entrant and incumbent can take place in the shadow of potential product market competition. During this bargaining round, the threat of product market entry by the entrant is countered by the threat of expropriation by the incumbent. Specifically, we allow incumbents to continue to invest in research during the bargaining phase and, with some probability, develop a work-around (imitative) technology that serves to expropriate the entrant's rents from successful innovation.[2] The inclusion of this non-cooperative bargaining game (and the possibility of weak property rights) allows us to provide a more complete treatment of the bargaining parameters than prior work and allows the equilibrium licensing fee to be determined by economic parameters. As well, this solution provides a precise characterization of the economic drivers of equilibrium research intensity when licensing is an option and identifies the impact of ex-post licensing on ex-ante research incentives.

We derive four key insights. First, under the informational and product market payoff assumptions from the patent race literature, technology licensing is not only feasible but is the unique equilibrium. In the absence of noncontractible information asymmetries between the incumbent and entrant, observations of entry into the product market therefore represent something of an economic puzzle.

Second, the nature of knowledge spillovers and the relative strength of intellectual property rights play an important role in the determination of license fees. When property

[2] The importance and prevalence of expropriation has been suggested by, among others, Levin, et. al.

rights are "weak," incumbents can (credibly) threaten to continue to research during the bargaining phase, raising the incumbent's effective bargaining power. In this respect, our model suggests a *purely strategic incentive* for incumbents to develop research capabilities -- to influence the share of rents they capture, even when the majority of innovation is licensed from external sources.

Third, when licensing is possible, the relative research intensity of incumbent and entrant depends on a simple *willingness to pay* (or WTP) condition (i.e., what is the maximum bid that either party would be willing to make to control the innovation immediately?).[3] For the entrant, its WTP is the license fee; for the incumbent, it is the difference between their pre and post innovation monopoly profits. This condition allows us to characterize a number of special cases. For example, when entry into the product market is not a credible threat during negotiations (as would occur when the fixed costs of entering the product market are sufficiently high), the incumbent's WTP is higher than that of the entrant; consequently, the incumbent will research more intensively than an entrant in this setting.

Finally, the model provides clear predictions about the nature of strategic interactions between incumbent and entrant. For entrants, the structure of strategic interaction resembles the forces highlighted by the traditional patent race literature; that is, entrants' incentives for research are always increasing in the level of incumbent research (i.e., strategic complements). In contrast, the incumbent's response to changes

(1987) and Teece (1987) and has been studied more recently by Anton and Yao (1994).

[3]This contrasts with the traditional patent racing literature, where relative research intensity depends on the relative salience of the incumbent's desire for preemption (Gilbert and Newbery, 1982) versus the "replacement" effect (Arrow, 1962; Reinganum, 1983). When licensing is possible, the pre-emption incentives are equalized (a point first noticed by Salant (1984)), yielding our more simple condition.

in the level of research investment by the entrant can increase or decrease, depending on the expected size of the licensing fee. In particular, when the licensing fee is high (e.g., when the entrant can credibly threaten to compete in the product market), the incumbent's reaction to entrant research satisfies strategic complementarity, similar to the previous literature. However, when the licensing fee is sufficiently small, the incumbent prefers increased entrant research; rival R&D exerts a positive externality. As such, the incumbent considers entrant research as an imperfect substitute for in-house research, resulting in strategic substitutability between incumbent and entrant research.

The plan of the paper is as follows. In the next section, we introduce the model, building on Reinganum's canonical model of technological competition. Section III then considers the non-cooperative bargaining game that results when an entrant innovates before an incumbent. Using the results from this bargaining stage, we work backwards to consider the innovation race between an incumbent and an entrant (Section IV) and analyze the relative research intensities of incumbent and entrant and the nature of their R&D rivalry. Section V briefly expands on our treatment of information disclosure. A final section concludes.

II. Model Set-Up and Assumptions

Players and Timeline

Two firms – an incumbent monopolist (*I*) and a potential entrant (*E*) – can potentially generate and commercialize an innovation. In order for *E* to earn profits, it must develop the innovation prior to *I*. The game is divided into two broad stages (see Figure 1). Stage 1 is composed of a continuous-time investment game in which each firm chooses a research intensity, x_i, which, with some probability, yields a single innovation and thereby ushers in Stage 2.[4] If the innovation has been discovered by *I*, then *E* is discouraged from further research, *I* maintains its monopoly in the product market, and the game ends. If the innovation has been discovered by *E*, then *E* can either (a) enter the product market and compete with *I* or (b) bargain with *I* over whether to license the innovation.[5] During the course of bargaining, *I* can continue researching (attempting to come up with a work-around technology) and *E* can choose to break off negotiations and enter the product market. Our analysis derives subgame perfect equilibria of this game and examines the comparative statics of each firm's strategies at each stage. To do so, we first specify the underlying research investment technology, and our assumptions about the structure of product market payoffs before and after the innovation has been realized.

Research Investment Technology

In Stage 1, each firm faces the same "memoryless" research investment technology:[6,7] when a firm, *i*, expends $x_i\Delta$ between time *t* and $t + \Delta$, then an innovation is

---

[4] This stage follows the framework developed in Reinganum (1983) and reviewed in Reinganum (1989).

[5] In the traditional patent racing literature, Stage 2 is composed of product market competition between incumbent and entrant.

[6] Our use of a "memoryless" R&D investment technology involves a strong (though common) assumption about the nature of the discovery process (see Fudenberg, et.al. (1983) for an example involving a learning R&D technology). However, in contrast to models which focus on the specifics of the timing of R&D competition, we are interested in the determinants of ex-post licensing and the impact of licensing on underlying research incentives. As such, the specific functional form for the R&D investment technology is not critical for our results except insofar as it belongs in the class of models with uncertainty.

[7] Alternatively, the productivity of the entrant and incumbent could be asymmetric. As discussed in Henderson (1993), entrants may be more productive at competence-destroying innovation while incumbents may be more productive in achieving competence-reinforcing innovation. Alternatively, differences in

generated in that time with probability $h(x_i)\Delta$.[8] $h(.)$ is a twice continuously differentiable function with $h'(x_i) > 0$ and $h''(x_i) < 0$, for all $x_i \in [0,\infty)$, $\lim_{x_i \to 0} h'(x_i) = \infty$ and $h(0) = 0 = \lim_{x_i \to \infty} h'(x_i)$. Firms share the common discount rate, $\delta = e^{-r\Delta}$. For simplicity, we focus continuous time approximations as $\Delta \to 0$.

If E is the first to generate the innovation, Stage 2 is initiated and we allow I to continue its research efforts. The basic process of innovation remains the same in Stage 2 except the research productivity function for the incumbent becomes $\tilde{h}(x_I) = \theta h(x_I)$. θ is a knowledge spillover parameter that may be less than, equal to, or greater than one. If E's success improves the likelihood that I develops a substitute version of the innovation (as might occur if the innovation can be reverse-engineered) then $\theta > 1$.[9] On the other hand, if E is able to obtain at least some effective intellectual property protection, making it more difficult for I to develop a version of the innovation, the spillover is less than one (i.e., $\theta \in [0,1)$).[10] Through Sections III and IV, θ is treated as a pure spillover that is independent of E's strategy. However, our model also accommodate a more nuanced "disclosure effect" (along the lines of, for example, Anton and Yao (1995)) in which

research productivity could arise from the ability to provide R&D incentives (Holmstrom, 1989; Aghion and Tirole, 1994; Gans and Stern, 1999).

[8] Observe here that we use Δ as the length of time for decision-making rather than 1 (as in discrete time models) or *dt* (as in continuous time models). It is useful to solve the model by taking the limit as Δ approaches 0 (i.e., the discrete time solution as the period length becomes infinitesimally small).

[9] Katz and Shapiro (1987) consider positive spillovers as a result of one firm's success innovation. Their analysis does not model how this affects licensing fees, however. In contrast, our analysis below will incorporate this feature into the Stage 2 bargaining game (specifically, into each firm's outside options).

[10] The patent racing and licensing literatures usually assume that $\theta = 0$ (I cannot develop a 'work-around' innovation (Salant, 1984; Aghion and Tirole, 1994)), a case we refer to as strong intellectual property rights.

participation in licensing negotiations or product market entry specifically affects θ, a possibility we consider in Section V.

Payoff Structure

Prior to the use of an innovation in the product market, by either firm, the present value of *I*'s profits are $\pi^m(0)$. If *I* innovates prior to *E*, it earns monopoly profits, $\pi^m(1)$,[11] where the term in parentheses (0 or 1) denotes whether *I* controls the innovation (whether this control comes from licensing from the entrant or from internal development). If *E* is the first to innovate, it chooses between competing with *I* and bargaining with *I* over the terms of a licensing deal. If *E* and *I* agree to a licensing deal with fee τ, *E* earns τ and *I* earns $\pi^m(1)-\tau$. Alternatively, to compete with *I*, *E* must first incur a sunk entry cost, *K*.[12] Having done this entry cannot be reversed.[13] Until *I* develops a work-around version of the innovation, duopoly profits are equal to $\pi_E^d(0)$ and $\pi_I^d(0)$ for *E* and *I*, respectively. When *I* develops a work-around technology, duopoly profits shift to $\pi_E^d(1)$ and $\pi_I^d(1)$ (recalling how the term in parentheses denotes whether *I* controls the innovation).

---

[11] We assume that monopoly profits are symmetric, i.e., $\pi_I^m(1)=\pi_E^m(1)=\pi^m(1)$.

[12] We do not strictly require that *E* starts a production unit themselves; it could contract with a separate firm which faces a cost of *K* to commercialize the innovation (independent of any licensing arrangements between them).

[13] Under the U.S. antitrust law, mergers between competitors is much more difficult when they are engaging in product market competition. For example, the DOJ and FTC will oppose licensing if it results in a potential entrant choosing not to become a productive competitor to an incumbent (USDOJ, 1995).

Key Assumptions about Product Market Payoffs

We make three straightforward but substantive assumptions about these product market payoffs:

(A1) $\pi^m(1) \geq \pi^m(0)$;

(A2) $\pi^m(1) \geq \pi_I^d(0) + \pi_E^d(0)$ and $\pi^m(1) \geq \pi_I^d(1) + \pi_E^d(1)$;

(A3) $\pi_E^d(1) < K$.

Monopoly under the innovation is value-enhancing (A1). Moreover, regardless of whether *I* has access to the innovation or not, monopoly profits with the innovation are greater than the sum of duopoly profits (A2). Finally, under (A3), *E* finds it unprofitable to enter into production once *I* has control over the innovation (whether that control arises from licensing or from the success of their own in-house research), and so discontinues research once that event occurs. Taken together, (A1) - (A3) allow us to explore a model of technological competition where innovation can impact market structure (as occurs if *E* innovates and invests *K*) but ex-post licensing by *E* may be privately valuable.

III. Bargaining Over the License Fee

This section derives the solution to Stage 2 of the game when *E* is the first to generate the innovation in Stage 1.[14] The bargaining model we develop both incorporates several key insights from the R&D licensing literature and remains integrated with the continuous-time R&D investment game from Stage 1. More specifically, our model

[14] If *I* is first to generate the innovation in Stage 1, then, by (A3), *E* chooses to discontinue research and the game is over.

addresses how the nature of knowledge spillovers and the consequent strength of property rights impacts bargaining by allowing *I* to continue researching after *E*'s success. After *E*'s success, the R&D investment technology available to *I* can become more or less efficient, depending on the relative strength of IP rights versus knowledge spillovers.

This feature requires that we develop the bargaining structure somewhat carefully. Since additional R&D expenditures can yield a competing innovation with similar economic value (as long as $\theta > 0$), the bargaining protocol must include a stage in which *I* can invest in R&D and, with some probability, change its outside option (by successfully developing the innovation in-house).[15] To do so, we adopt a bargaining framework in which negotiation takes time and delay is costly (Rubinstein, 1982; Sutton, 1986; Wolinsky, 1987). In this setting, the bargaining solution depends on the outside options and impatience of each party, and the structure of the bargaining protocol.

Bargaining Protocol

Once *E* has developed the innovation (but *I* has not yet done so), there is an opportunity to participate in a bargaining stage over a potential licensing agreement. The extensive form for this bargaining process is depicted in Figure Two. The bargaining protocol is symmetric; at the beginning of each time period, Nature randomly chooses the offering party (*I* or *E*).[16] The chosen party makes an offer of a license fee, τ_i (where *i* is the offeror), for which *E* will sell the innovation to *I*. If this offer is accepted, then the game ends and *E* receives τ_i while the incumbent receives, $\pi^m(1) - \tau_i$. If this offer is

[15] By allowing parties to search for outside options during negotiations, the bargaining protocol is therefore very similar to Wolinsky (1987).

rejected, *I* continues its research activity. If this research is successful, *I* adopts the innovation, receives $\pi^m(1)$, and the game ends with *E* receiving nothing. If *I* is unsuccessful, the next period of bargaining begins with Nature choosing another offeror. Finally, *E* can sink *K* and compete in the product market (a) prior to the commencement of negotiations or (b) following an offer by the incumbent.[17,18] The equilibrium bargaining solution depends on each party's outside options at each stage of bargaining, and so we characterize these conditions before solving for the Stage 2 equilibrium.

Outside Options of E

E's outside option depends critically on whether entry is *credible*, in the sense that the sunk costs of entry, *K*, are less than *E*'s expected duopoly profits. When entry is *not* credible, *E*'s outside option is equal to zero. In contrast, when entry *is* credible, *E* can choose to incur *K* and enter the product market, and expect to earn $\bar{V}_E$. $\bar{V}_E$ depends on the expected lengths of (a) a period of favorable duopoly, in which *E* earns $\pi_E^d(0)$ as the sole supplier of a good which incorporates the superior technology, and (b) a less favorable follow-on period after *I* successfully generates a version of the innovation where *E*'s profits decline to $\pi_E^d(1)$. In other words, unless intellectual property rights are perfectly strong *($\theta = 1$)*, $\bar{V}_E$ will depend on x_I, the expected level of R&D investment by *I*

---

[16] By symmetrizing the extensive form game, we do not separately have to model how incentives to continue research depend on who is the offeror in the next period (Shaked, 1994).

[17] If *E* can begin production at any time, then *E* can threaten to begin production if its own offers are not accepted. While not substantively different than the current set-up, this results in a continuum of equilibria, complicating the analysis of the innovation game below (Osbourne and Rubinstein, 1990; Shaked, 1994).

[18] As a simplifying assumption (which is not critical to any of our main analytical results), we have assumed that once the entrant has entered the product market, the incumbent and entrant do not collectively gain from licensing. This possibility creates more cases with no new insights and therefore we relegate the analysis of this case to footnotes throughout the rest of this section (see footnotes 20 and 21).

after entry by *E*. Given the assumed stationarity of the discovery process, we can solve for $\bar{V}_E$:[19]

$$\bar{V}_E = \frac{r\pi_E^d(0) + \theta h(x_I^*)\pi_E^d(1)}{r + \theta h(x_I^*)},$$

where x_I^* is the research intensity chosen by *I* to maximize its expected payoff when faced with entry. As a result, for *I*, its competitive payoff, $\bar{V}_I$, can be derived as:

$$\bar{V}_I = \frac{r\pi_I^d(0) - x_I^* + \theta h(x_I^*)\pi_I^d(1)}{r + \theta h(x_I^*)}.$$

It is useful to note that while both *E* and *I* earn positive profits in this case, (A1) and (A2) imply that $\pi^m(1) > \bar{V}_I + \bar{V}_E - K$, so that there are mutual gains to be had from *E* not beginning production and instead licensing the innovation to the incumbent.[20] Similarly, when $\bar{V}_E < K$ (*E* cannot credibly threaten to enter the product market), *I*'s expected profit from continuing research is less than the value from immediately acquiring the technology from *E* (i.e., $\pi^m(1) > \bar{V}_I + 0$).

Outside Options of I

While *E*'s entry choice is irreversible, *I*'s outside options during a period of bargaining disagreement depend on the period-to-period level of R&D that *I* credibly

[19] Note that $V_E(x_I) = \theta h(x_I)\Delta\pi_E^d(1) + (1 - \theta h(x_I)\Delta)\left((1-\delta)\pi_E^d(0) + \delta V_E(x_I)\right)$. Solving for *E*'s expected payoff we have: $V_E(x_I) = \left((1-\delta)\pi_E^d(0) + \theta h(x_I)\Delta\pi_E^d(1)\right) / \left(1 - \delta(1 - \theta h(x_I)\Delta)\right)$. Substituting in x_I^* and taking the limit as Δ approaches 0 yields the expression for $\bar{V}_E$.

[20] Our assumption that *E* does not have an incentive to license once it has entered the product market is therefore simply the condition, ($\pi_I^d(1) + \pi_E^d(1) < \bar{V}_I + \bar{V}_E$). When this condition is relaxed, the relevant outside options associated with entering the product market are those that would result when *I* and *E* bargain over a horizontal license as duopolists.

threatens to undertake during periods of disagreement. To see the effect of this, consider the solution where *I* expects to accept τ_E or offer (and have accepted) τ_I in the next round of negotiations (each of these outcomes will occur with equal probability). After a rejection, then, the incumbent's expected payoff is:

$$\theta h(x_I)\Delta\pi^m(1) + \left(1-\theta h(x_I)\Delta\right)\left((1-\delta)\pi^m(0) + \delta\left(\pi^m(1) - \tfrac{1}{2}\left(\tau_E + \tau_I\right)\right)\right) - x_I\Delta \, .$$

I's continued research makes it possible that an innovation could be generated with it realizing $\pi^m(1)$. If no innovation is forthcoming during a disagreement period, *I* earns the old monopoly profits and expects to reach a licensing agreement in the following period. *I* will have an incentive to choose a research intensity to maximize this payoff and potentially pre-empt the need for any future agreement with *E*. *I*'s ability to undertake further research weakens *E*'s bargaining position.

Equilibrium of the Bargaining Game

Given the outside options for each player and the bargaining protocol given above, we are able to characterize the unique equilibrium of this bargaining game letting $\delta = e^{-r\Delta}$ and exploring the limiting solution as Δ approaches zero:

Proposition 1. *Assume (A1) to (A3) and* $\pi_I^d(1) + \pi_E^d(1) < \overline{V}_I + \overline{V}_E$.[21] *Then the continuous time bargaining game described above has a unique subgame perfect equilibrium with an*

---

[21] If $\pi_I^d(1) + \pi_E^d(1) \geq \overline{V}_I + \overline{V}_E$, then upon entry, *I* and *E* will continue negotiations during duopoly. As entry is irreversible, the unique subgame perfect equilibrium for this case results in an offer and acceptance of:

$$\tau = \max\left[\frac{\left(\pi^m(1) - \pi^m(0)\right)r + \tilde{x}_I(m)}{2(\theta h(\tilde{x}_I(m)) + r)}, \frac{\left(\pi_I^d(1) + \pi_E^d(0) - \pi_E^d(1) - \pi_I^d(0)\right)r + \tilde{x}_I(d)}{2(\theta h(\tilde{x}_I(d)) + r)} + \pi_E^d(1) - K\right],$$

where $\tilde{x}_I(m)$ and $\tilde{x}_I(d)$ are *I*'s choices of research intensity during negotiations when it is a monopolist and duopolist respectively. Thus, the feasability of duopoly licensing simply alters the constrained license fee. Note, however, that in this case entry could be credible even if $\overline{V}_E < K$, as the entrant also expects to earn τ upon entry. For a discussion of when this case might be considered realistic see Oster (1990, p.306).

agreement reached in the first round of negotiations and no production by the entrant. The offer made and accepted in the first round of negotiations is:

$$\tau = \max\left[\frac{\left(\pi^m(1)-\pi^m(0)\right)r+\tilde{x}_I}{2(\theta h(\tilde{x}_I)+r)}, \overline{V}_E - K\right],$$

where $\tilde{x}_I$ *is determined by* $\theta h'(\tilde{x}_I)\tau = 1$.

The proof is contained in the appendix. The existence of a unique licensing equilibrium (and the deterrence of entry into the product market) depends only on the assumption that monopoly profits are greater than duopoly profits. While higher spillovers (larger θ) and commercialization costs enhance the bargaining position of *I*, gains from licensing are present (and achievable) even if commercialization is costless and intellectual property rights are strong.[22]

A key insight from this framework is that, under weak property rights ($\theta > 0$), the threat of continued R&D by *I* reduces the equilibrium license fee and creates a *purely strategic* incentive to develop an R&D capability. Imitative R&D serves to increase the "patience" of incumbents, raising the share of the rents they can appropriate from independent innovation.[23] This strategic effect is complementary to alternative explanations for the development of an R&D capability in cases where external technology acquisition is an important part of the firm's overall strategy (e.g., the

[22] To see this more clearly, suppose intellectual property rights are strong and so *I* cannot threaten to do R&D (e.g., $\theta = 0$). This constraint on *I* serves only to change the level of the equilibrium license fee and not the qualitative outcome of licensing. For example, when entry is not credible under strong property rights, $\tau = \frac{1}{2}\left(\pi^m(1)-\pi^m(0)\right)$. This is precisely the solution provided by Aghion and Tirole (1994), who consider the division of returns from an innovation produced by an independent research team in the absence of in-house research capability. Alternatively, even if the innovation has no value to *I* per se, $\pi^m(1) = \pi^m(0)$ but entry is credible ($\overline{V}_E \geq K$), *I* is willing to pay purely for the maintenance of a monopoly market structure ((A3) ensures that *I* will only pay once for the innovation (Rasmusen, 1988)).

[23] This strategic effect can also be derived in the context of a model of vertical integration where partial integration allows a monopsonist to prevent renegotiation with some suppliers to gain bargaining levergage over remaining independent suppliers (de Fontenay and Gans, 1999; Gans, 1999).

bounded rationality justification – *absorptive capacity* – emphasized in Cohen and Levinthal (1990)).

Proposition 1 also highlights the impact that a credible entry threat has on license fee determination. When entry is not credible, we call the license fee *unconstrained*, since the bargaining solution depends solely on impatience (which is implicitly determined by the threat of in-house R&D success) and the underlying value of the innovation. In contrast, when *E* can credibly threaten to enter production, the equilibrium licensing fee may be *constrained* to be at least as high as this outside option. Indeed, since the exercise of this outside option is an irreversible act on *E*'s part, the equilibrium fee will shift up to precisely the value of this outside option (Osborne and Rubinstein, 1990, p.56).

Comparative Statics

The key comparative statics of this bargaining solution depend on the fact that the two endogenous variables are inversely related to each other; while an (exogenous) increase in τ increases the equilibrium level of $\tilde{x}_I$, (exogenous) increases in $\tilde{x}_I$ reduce the equilibrium level of τ. Higher license fees provide higher incentives to engage in in-house R&D, while higher effort by *I* reduces the share of rents from innovation that accrue to *E*.

Proposition 2. *The equilibrium level of* τ *is non-decreasing in* $\pi^m(1)$, $\pi_E^d(1)$, $\pi_I^d(1)$, $\pi_E^d(0)$ *and r; and is non-increasing in* θ, $\pi^m(0)$, $\pi_I^d(0)$ *and K.*

On *E*'s part, bargaining power is shaped by the sunk costs of commercialization and the structure of duopoly profits. *I*'s bargaining power, on the other hand, is increasing in the presence of positive knowledge spillovers and the presence of a strong stream of current profits $(\pi^m(1)-\pi^m(0))$. Arrow's replacement effect (the reduced incentives of *I* to introduce new technologies which, at least in part, simply replace current rents) manifests itself here by allowing *I* to acquire competitive technologies at a reduced price.

IV. The Innovation Race

This section evaluates two central questions in the economic analysis of R&D competition: (a) Does the incumbent or the entrant do more R&D? (b) Are the R&D investments of incumbent and entrant strategic complements or substitutes? We answer these questions in the context of the canonical model of technological competition under uncertainty (Reinganum, 1983; 1989) – except that innovation by the entrant is followed by the bargaining game described in Section III rather than the product market competition assumed in the previous literature. By closely following the structure of prior work, we highlight the pure effect of a "market for ideas" on R&D investment incentives.[24]

Our discussion begins by specifying the payoff functions of both firms. Each firm chooses a level of R&D investment at each moment in time, weighing the present costs of this R&D versus the discounted value of successful innovation (by either firm). Given the assumed stationarity of the research technology, the expected payoffs for *E* and *I* can be written as:

$$V_E(x_I, x_E) = \int_0^{\infty} e^{-rt} e^{-(h(x_I)+h(x_E))t} \left(h(x_E)\tau - x_E\right) dt = \frac{h(x_E)\tau - x_E}{r + h(x_I) + h(x_E)}$$

---

[24] Several other interesting questions can be straightforwardly analyzed in this framework, including the impact of pre-innovation incumbent profits (the replacement effect), the impact of learning over time or

$$V_I(x_I, x_E) = \int_0^\infty e^{-rt} e^{-\left(h(x_I)+h(x_E)\right)t} \left(r\pi^m(0) - x_I + h(x_I)\pi^m(1) + h(x_E)\left(\pi^m(1) - \tau\right)\right) dt$$
$$= \frac{r\pi^m(0) - x_I + h(x_I)\pi^m(1) + h(x_E)\left(\pi^m(1) - \tau\right)}{r + h(x_I) + h(x_E)}$$

The asymmetry between the *I* and *E* payoff functions (at the heart of the rest of our analysis) arise from the fact that (1) *I* receives $\pi^m(0)$ until the innovation is brought into the market, (2) *E*'s payoff from their own successful innovation (τ) is different than *I*'s ($\pi^m(1) - \pi^m(0)$), and (3) the expectation of licensing in the case of successful entrant innovation implies that *I*'s payoff in that case is simply $\pi^m(1) - \tau$.

The equilibrium of the model is characterized by two equations.

Proposition 3. *Assume (A1) to (A3). Then the continuous time R&D investment game has a subgame perfect equilibrium (* $\hat{x}_I$ *,* $\hat{x}_E$ *) which is the solution to:*

$$h'(\hat{x}_I)\left(h(\hat{x}_E)\tau + r\left(\pi^m(1) - \pi^m(0)\right)\right) = r + h(\hat{x}_E) + h(\hat{x}_I) - h'(\hat{x}_I)\hat{x}_I$$

$$h'(\hat{x}_E)\left(h(\hat{x}_I)\tau + r\tau\right) = r + h(\hat{x}_I) + h(\hat{x}_E) - h'(\hat{x}_E)\hat{x}_E\ ,$$

The two equations come from each firm's first order conditions. Both firms are torn between a desire to smooth research expenditures over time and a desire to realize the gains from innovation sooner as opposed to later. The benefits to concentrating research effort earlier in time are tied to the impatience of each firm (*r*) and the intensity of research effort by their rival.

(a) Does the incumbent or the entrant do more R&D?

The left hand side of the equilibrium equations in Proposition 3 describe the marginal benefit to current research: an interaction with the probability that the other firm

across research teams. Of course, each of these results depends on the specific assumptions underlying any successfully innovates (the *pre-emption* effect) and an interaction reflecting the rents to be realized from successful innovation in the absence of strategic concerns (the *willingness-to-pay* effect).[25]

The pre-emption effect reflects the marginal return to generating an innovation first and pre-empting the other team: winning as opposed to losing the innovation race. *E* receives no return when they lose, so this incentive is simply τ. *I* receives $\pi^m(1)$ if they win and $\pi^m(1)-\tau$ otherwise, yielding a pre-emption incentive of τ as well. Thus, under the equilibrium in Proposition 1, the pre-emption incentives in Stage 1 are equalized.[26]

The second component of the marginal benefit to research arises from the existence of positive rents from innovation: this element interacts with *r* and reflects the desire of each agent to generate an innovation even in the absence of R&D rivalry. By increasing research intensity, these rents can be earned sooner. For *E*, this means earning the license fee τ, while for *I*, successful innovation means that it earns $\pi^m(1)$ rather than $\pi^m(0)$. These are each firm's *willingness to pay* (WTP) motives since they reflect the value to each firm of gaining immediate control over the innovation.

The WTP motive is the sole asymmetry between *I* and *E*'s equilibrium first order conditions, yielding a simple condition describing the relative research intensities of each.

Proposition 4. *In equilibrium, the incumbent does less research than the entrant (i.e.,* $\hat{x}_I \le \hat{x}_E$*) if and only if* $\pi^m(1)-\pi^m(0)\le\tau$.

---

model of technological competition under uncertainty.

[25] Our organization of the effects which determine relative research intensity follows the conceptual distinctions develop by Katz and Shapiro (1987). The only difference is that we use the term "willingness to pay" rather than "stand-alone" to describe the incentives of firms to research in the absence of technological rivalry.

[26] This equalization has been observed in various forms by other researchers (e.g., Salant (1984) and Aghion and Tirole (1994)), and it stands in contrast to the traditional patent race literature where *I*'s pre-emption incentives always exceed those of the entrant (Gilbert and Newbery, 1982).

Proposition 4 suggest that factors which affect the bargaining equilibrium in Stage 2 (*K*, *θ*, and duopoly product market payoffs) can affect the relative research intensities of *I* and *E* through their influence on *τ*.[27]

For example, consider the determination of relative research intensities when the license fee is *unconstrained*. In this case, the upper bound on τ is $\frac{1}{2}\left(\pi^m(1) - \pi^m(0)\right)$ achieved when $\theta = 0$. This is clearly less than *I*'s WTP, yielding the following implication:

Corollary 1. *If* τ *is unconstrained, then* $\hat{x}_I > \hat{x}_E$.

In other words, when entry is not credible, an incumbent will do more research than a single entrant, no matter how radical the innovation.

Alternatively, consider the case of a drastic innovation ($\pi^m(1) = \pi^d_E(0)$ and $\pi^d_I(0) = 0$) in an environment where entry barriers are sufficiently low (so that product market entry is credible) and intellectual property is sufficiently strong. The drasticness of the innovation raises the WTP motive of *E* while dampening the incentives of *I*.

Corollary 2. *If the innovation is drastic, K = 0 and θ = 0, then* $\hat{x}_E > \hat{x}_I$.

This result, though similar to the previous literature, suggests some important checks on prior findings. In particular, radicalness per se will only result in higher intensity for *E* when the sunk costs to product market entry are small and intellectual property is sufficiently strong.

---

[27] For example, an increase in *K* (weakly) reduces the equilibrium level of τ, thereby increasing the research intensity of the incumbent relative to the entrant.

(b) Are R&D investments strategic complements (or substitutes)?

In the traditional patent race literature, incumbent and entrant engage in an R&D "race" – x_I and x_E are both strategic complements with each other.[28] This characterization (along with its implications for "overinvestment" in R&D) is a distinctive contribution and prediction of the literature on technological competition, with implications for empirical work (Cockburn and Henderson, 1995; Lerner, 1997), macroeconomic modelling of technological change (Jones and Williams, 1996) and public policy (Green and Scotchmer, 1995). The key to this prediction arises because, in traditional models of technological competition, the expected profits of each firm are declining in the research effort of rivals (i.e., rival investment exerts a negative externality).

Recall that the marginal benefit of additional research is to raise the probability of earning the payoff from successful innovation rather than the expected payoff from a continuation of the innovation race, V_i. In the traditional literature (without licensing), increases in the research intensity of rivals lowers V_i. Whether research investment satisfies strategic complementarity or substitutability depends on the sign of the mixed partial derivative of a firm's payoff function with respect to own and rival research intensity. The sign of this is equivalent to the negation of the size of the externality.[29] In other words, findings of strategic complementarity in the prior literature are directly

---

[28] That is, as one agent raises its research intensity, this makes it optimal for the other agent to raise his R&D intensity in response (Reinganum, 1983). As in the previous literature on technological competition (e.g., Loury, 1980; Lee and Wilde, 1980; Reinganum, 1989), when we discuss strategic complementarity and strategic substitutability, we are talking of a local condition on the reaction curves of the firms around the equilibrium and not a global characteristic of the mixed partial derivatives of the payoff functions.

[29] Note that, in our notation, for a patent race model without licensing $\frac{\partial^2 V_E}{\partial x_E \partial x_I} = \frac{h'(x_I)}{h(x_E)+h(x_I)+r}\left(\frac{h'(x_E)(\pi_E^d(0)-V_E)-1}{h(x_E)+h(x_I)+r} - \frac{\partial V_E}{\partial x_I}\right)$ and $\frac{\partial^2 V_I}{\partial x_I \partial x_E} = \frac{h'(x_E)}{h(x_E)+h(x_I)+r}\left(\frac{h'(x_I)(\pi^m(1)-V_I)-1}{h(x_E)+h(x_I)+r} - \frac{\partial V_I}{\partial x_E}\right)$ where in each case the first bracketed term is zero by each firm's respective first order conditions.

related to their implicit assumption that increased research effort by rivals exerts a negative externality on individual firms.

In the context of our model, *E*'s expected payoff is decreasing in *I*'s R&D effort since this increases the probability that *E* will earn no rents from its own R&D effort. This negative externality ensures that *E*'s research effort is non-decreasing in x_I.[30]

From *I*'s perspective, however, increased research intensity by *E* may exert a positive or negative externality,

$$\frac{\partial V_I}{\partial x_E} = \frac{h'(x_E)}{h(x_E)+h(x_I)+r}\left(\pi^m(1)-\tau-V_I\right).$$

Under Proposition 1, successful innovation by *E* yields an immediate return of $\pi^m(1)-\tau$ to *I*. If the rents from licensing are greater than V_I, the pre-innovation expected payoff, then *E*'s research serves as an imperfect substitute for *I*'s own R&D. Consequently, *I* accommodates increased *E* research intensity by reducing its own research effort. Our main finding can be summarized as follows:

Proposition 5. *Entrant research effort is non-decreasing in incumbent research effort. Incumbent research effort is non-decreasing in entrant research effort if* $V_I(x_I, x_E) \geq \pi^m(1)-\tau$ *and non-increasing if* $V_I(x_I, x_E) \leq \pi^m(1)-\tau$.

An interesting implication of Proposition 5 is that the determination of strategic substitutability depends on whether *I* "prefers" increased research intensity by *E* in the sense that *I*'s value function is increasing in x_E. More generally, Proposition 5 suggests that *I* has incentives to provide direct subsidies to external researchers in the expectation

30 Note that, in our notation, in our model $\frac{\partial^2 V_E}{\partial x_E \partial x_I} = \frac{h'(x_I)}{h(x_E)+h(x_I)+r}\left(\frac{h'(x_E)(\tau-V_E)-1}{h(x_E)+h(x_I)+r} - \frac{\partial V_E}{\partial x_I}\right)$ and $\frac{\partial^2 V_I}{\partial x_I \partial x_E} = \frac{h'(x_E)}{h(x_E)+h(x_I)+r}\left(\frac{h'(x_I)(\pi^m(1)-V_I)-1}{h(x_E)+h(x_I)+r} - \frac{\partial V_I}{\partial x_E}\right)$ where in each case the first bracketed term is zero by each firm's respective first order conditions.

of ex-post licensing and that such subsidies have a negative impact on own R&D spending.

The empirical relevance of Proposition 5 can be highlighted by examining several special cases. For example, when the costs of entering the product market are high enough so that the license fee is unconstrained (see Proposition 1), *I* is able to retain a sufficient level of bargaining power to ensure that they are better off when *E* innovates than when neither firm innovates.

Corollary 3. *Suppose that* $\theta \geq 1$.[31] *If the license fee is unconstrained, then the incumbent's research effort is a strategic substitute for entrant research.*

An immediate implication of Corollary 3 is that there exists some region where the license fee is *constrained* and *I* behaves according to strategic substitutability.[32] In other words, one of the principal empirical implications of the traditional literature – strategic complementarity in research – does not necessarily hold when licensing is feasible, even when product market competition is credible.

In contrast, when the innovation is drastic, there are no costs to product market entry and there are strong intellectual property rights, the equilibrium license fee is the full value of the monopoly; in that case, the expected payoff for *I* is decreasing in the level of *E* research.

Corollary 4. *If the innovation is drastic,* $K = 0$ *and* $\theta = 0$*, then the incumbent's research intensity is a strategic complement for entrant research.*

---

[31] This is a sufficient condition only. It may be possible that property rights may be perfect but strategic substitutability still results.

[32] Since τ is continuous in *K*, one can consider the case where the unconstrained and constrained licensing fees are equal. A small decrease in *K* implies that the licensing fee is now constrained but that the inequality constraints in Corollary 3 still hold.

The two extreme cases of corollaries 3 and 4 highlight the more general relationship in models of technological competition under uncertainty; strategic complementarity goes hand-in-hand with the presence of a negative externality in R&D across firms. To the extent that firms prefer no innovation to innovation by a competitor, their reaction to greater R&D by that competitor will be increasing (and the converse also holds).

V. The Case of Endogenous Knowledge Spillovers

We now briefly discuss the case where knowledge spillovers ($\theta > 1$) only occur when *E* chooses to begin negotiations with *I*. In this sense, we consider a case where information disclosure during bargaining is important but reverse-engineering is costly. As emphasized by Anton and Yao (1994, 1995), the disclosure problem is extremely important in many R&D settings and they suggest that a key source of rents for the entrant is the availability of a competitive outside option. This insight is analogous to the difference in our analysis highlighted between the constrained and unconstrained cases. Indeed, it is easy to show that, in the unconstrained case, the presence of an endogenous disclosure effect simply reduces the licensing fee earned by *E* and reduces the relative research intensity of *E* (and, by the strategic substitutability satisfied in this case, increases the research intensity of *I*).

In contrast, when the licensing fee is constrained by post-entry profits, *I* has an incentive to enhance the ex post disclosure bargaining power of *E*. This is because in the absence of an enhanced bargaining position, *E* earns exactly $\overline{V}_E - K$ by going into the product market. Under an endogenous disclosure effect, once negotiations start, the best offer that *E* can ensure for itself is $\tilde{V}_E - K$, where $\tilde{V}_E$ is the expected value of entrant profits if negotiations break down and the incumbent is able to conduct his own research with the "improved" research technology. Since $\tilde{V}_E < \overline{V}_E$, negotiations cannot happen unless *I* offers a bargaining protocol that keeps *E* indifferent to entering the product market (such as offering a fixed fee "negotiation bonus" equal to $\overline{V}_E - \tilde{V}_E$). Interestingly, since the innovation incentives are being kept constant, under the constrained case, there is no effect on the R&D incentives of either *E* and *I*. Similar to the spirit of Anton and Yao, our model suggests that, when *E* has some outside options, equilibrium payoffs will ultimately be driven by product market payoffs rather than the specifics of the bargaining protocol.

VI. Concluding Thoughts

We conclude by speculating about how the potential for product market cooperation, a relatively common mechanism by which research-oriented start-up firms earn their economic returns, impacts two classic Schumpeterian questions about the relationship between innovation and entry.

How do entrants and incumbents differ in their incentives for innovative investment?

The returns on innovative investment can be realized in two distinct ways – through the product market or through the ideas market. When both of these avenues are available, the main difference between entrants and incumbents is that while entrants will earn their rents through contracting, incumbents will realize their returns on innovative investments through the product market. Whereas entrants are always made worse off by the success of the incumbent (as this reduces the joint gains from contracting), the reverse need not be the case. Incumbents can offer a share of the pie associated with the continuation of monopoly market structure; in so doing, incumbents can benefit from innovation that takes place outside of the firm. A principal consequence of this asymmetry is that the difference among incumbents and entrants in terms of their willingness-to-pay for successful innovation is a comparison of the value of a contract to an outsider versus the incremental market profits to be earned by a monopolizing incumbent. Therefore, when licensing is an option, auxiliary factors will simply affect the particular price at which the license is realized. For example, though changes in the environment surrounding pharmaceutical innovation have changed the relative bargaining power of biotechnology versus established pharmaceutical firms, such changes have not impacted the basic result that biotechnology firms tend to contract with established firms in order to commercialize their technologies. Thus, the qualitative difference in the means by which incumbents and entrants earn returns on innovation (the product market versus the ideas market) persists and remains at the heart of the difference between these agents in terms of their underlying innovation incentives.

How does technological change affect market structure?

Since Schumpeter, there has been a presupposition that, to the extent that entrants have sufficient incentives and means to conduct R&D in the first place, technological innovation is a powerful instrument of "creative destruction" and the dislodging of incumbent market power. Instead of disputing this assertion, we argue the negative result that the economic foundations of this belief have not yet been fully articulated. Most previous research on technological competition essentially assumes the procompetitive effects of successful entrant innovation. In contrast, this paper suggests that, in the absence of a knowledge disclosure problem which cannot be overcome by through an appropriate bargaining protocol, there is no particular bar to – and strong incentives for – a licensing solution which maintains monopoly market structure. While one could consider alternative specifications of the particular structure of the game we analyze, the main result is robust – under the assumptions of the prior literature on R&D incentives, innovation has no effect on observed market structure. It seems that understanding the gale of creative destruction will involve more nuanced evaluation of the relationship between R&D incentives and the nature of property rights over knowledge. In the spirit of recent work by Anton and Yao (1994; 1995), we speculate that observing competition in product markets where innovation is important is suggestive of an earlier market failure – in the "market for ideas."

Appendix

Proof of Proposition 1:

The proof proceeds in steps (along the lines of Wolinsky, 1987, Proposition 1). First, we look at the game assuming that *E* does not wish to begin production at any stage. Then we turn to consider the full game in which entry is an option for *E*.

<u>Step One</u>: Suppose first that *E* does not wish to begin production either before or during negotiations. Following Wolinsky (1987), given (A1), the subgame equilibrium is characterized by the following equations:

$$\pi^m(1)-\tau_E=\theta h(\tilde{x}_I)\Delta\pi^m(1)-\tilde{x}_I\Delta+\left(1-\theta h(\tilde{x}_I)\Delta\right)(1-\delta)\pi^m(0)$$
$$+\left(1-\theta h(\tilde{x}_I)\Delta\right)\delta\left(\pi^m(1)-\tfrac{1}{2}\left(\tau_E+\tau_I\right)\right)$$

$$\tau_I=\left(1-\theta h(\tilde{x}_I)\Delta\right)\delta\tfrac{1}{2}\left(\tau_E+\tau_I\right)$$

$$\theta h'(\tilde{x}_I)\left(\left(\pi^m(1)-\pi^m(0)\right)(1-\delta)+\tfrac{1}{2}\left(\tau_E+\tau_I\right)\delta\right)=1\,.$$

The first equation states that *E*'s offer to *I* must be at least as high as *I*'s expected payoff if they reject the offer. The second is the equivalent condition when *I* is the offeror. The final equation is the first order condition for *I*, maximizing their disagreement payoff. This determines $\tilde{x}_I$, *I*'s research intensity during negotiations. Note that $\tilde{x}_I$ is unique.

Solving these equations gives:

$$\tau_E=\left(\left(\pi^m(1)-\pi^m(0)\right)\left(1-\theta h(\tilde{x}_I)\Delta\right)(1-\delta)+\tilde{x}_I\Delta\right)\frac{1-(1-\theta h(\tilde{x}_I)\Delta)\delta\,\frac{1}{2}}{1-(1-\theta h(\tilde{x}_I)\Delta)\delta}$$

$$\tau_I=\left(\left(\pi^m(1)-\pi^m(0)\right)\left(1-\theta h(\tilde{x}_I)\Delta\right)(1-\delta)+\tilde{x}_I\Delta\right)\frac{\left(1-\theta h(\tilde{x}_I)\Delta\right)\delta\,\frac{1}{2}}{1-(1-\theta h(\tilde{x}_I)\Delta)\delta}$$

These are offered and accepted during the first round of negotiations. That the equilibrium is unique follows from the uniqueness of the post-innovation choice of $\tilde{x}_I$ for

I. Given our assumption in this step that *E* does not enter into production, in the event of a breakdown, *E*'s payoff would be zero while *I* would earn $\max_{x_I} V_I(x_I)$ where:

$$V_I(x_I) = \frac{(1-\delta)\pi^m(0) + \theta h(x_I)\Delta\pi^m(1) - x_I\Delta}{1-\delta(1-\theta h(x_I)\Delta)}.$$

Wolinsky (1987) shows that $\pi^m(1) - \tau_I \geq \max_{x_I} V_I(x_I)$ and $\pi^m(1) - \tau_E \geq \max_{x_I} V_I(x_I)$.

Finally, looking in continuous time, if we replace δ with $e^{-r\Delta}$ and take limits as Δ approaches zero gives:

$$\tau_E, \tau_I \to \tau = \frac{\left(\pi^m(1) - \pi^m(0)\right)r + \tilde{x}_I}{2(\theta h(\tilde{x}_I) + r)}.$$

<u>Step Two</u>: Suppose now that *E* might enter into production. Given (A2), it is not in the interests of either party for *E* to begin production prior to negotiations. This option means that *E* can guarantee itself at least its outside option of $\overline{V}_E - K$. As in the solution of Osborne and Rubinstein (1990, Proposition 3.5, p.56), this constrains *I*'s offer to $\tau_I = \overline{V}_E - K$ for *K* sufficiently low. Solving for τ_E in this case and taking limits we obtain the (constrained) solution stated in the proposition.

Proof of Proposition 2

The proof hinges on the following lemma:

Lemma 1. $\operatorname{sgn}\frac{d\tau}{d\phi} = \operatorname{sgn}\frac{\partial\tau}{\partial\phi}$

PROOF: Note first that:

$$\frac{d\tau}{d\phi} = \frac{\partial\tau}{\partial\phi} + \frac{\partial\tau}{\partial x_I}\frac{d\tilde{x}_I}{d\phi}$$

$$\frac{d\tilde{x}_I}{d\phi} = -\frac{\theta h'(\tilde{x}_I)\frac{\partial\tau}{\partial\phi}}{\theta h''(\tilde{x}_I)\tau + \theta h'(\tilde{x}_I)\frac{\partial\tau}{\partial x}}$$

Note that $\theta h''(\tilde{x}_I)\tau + \theta h'(\tilde{x}_I)\frac{\partial\tau}{\partial x} \leq 0$. Substituting the first derivative in the second and rearranging we have:

$$\theta h''(\tilde{x}_I)\tau \leq (>) 0 \text{ if } \frac{\partial\tau}{\partial\phi} \geq (<) 0.$$

Thus, at the equilibrium $\tilde{x}_I$ changes in any parameter that raises τ taking x as given, raise τ in equilibrium. This result relies on the quasi-concavity of h(.). Using this lemma we have the proposition by taking simple partial derivatives. The comparative statics on $\pi_I^d(0)$, $\pi_E^d(0)$, $\pi_I^d(1)$ and $\pi_E^d(1)$ follow as $\overline{V}_I$ is non-decreasing in $\pi_E^d(0)$, $\pi_I^d(1)$ and $\pi_E^d(1)$ and non-increasing in $\pi_I^d(0)$.

Proof of Proposition 4:

Consider the first order conditions for a Nash equilibrium in the innovation game.

$$h(x_E)\left(h'(x_I)\tau-1\right)+r\left(h'(x_I)\left(\pi^m(1)-\pi^m(0)\right)-1\right)=h(x_I)-h'(x_I)x_I$$

$$\left(r+h(x_I)\right)\left(h'(x_E)\tau-1\right)=h(x_E)-h'(x_E)x_E$$

Suppose that x_I = x_E = x. If $\hat{x}_I \le \hat{x}_E$, the left hand side of the incumbent's first order condition, at x, must be lower than the right hand side, i.e.,

$$h(x)\left(h'(x)\tau-1\right)+r\left(h'(x)\left(\pi^m(1)-\pi^m(0)\right)-1\right)\le\left(r+h(x)\right)\left(h'(x)\tau-1\right)$$
$$\Rightarrow r\left(\pi^m(1)-\pi^m(0)-\tau\right)\le 0$$

This simplifies to $\pi^m(1)-\pi^m(0)\le\tau$, the condition of the proposition.

Proof of Proposition 5

Note that, $\frac{\partial^2 V_I}{\partial x_E \partial x_I}=\frac{h'(x_E)}{h(x_E)+h(x_I)+r}\left(\frac{h'(x_I)(\pi^m(1)-V_I)-1}{h(x_E)+h(x_I)+r}-\frac{\partial V_I}{\partial x_E}\right)$, where the first component of the bracketed term is zero by the incumbent's first order condition while for the second,

$$\frac{\partial V_I}{\partial x_E}=\frac{h'(x_E)}{h(x_E)+h(x_I)+r}\left(\pi^m(1)-\tau-V_I\right)$$

may be positive or negative depending on whether $\pi^m(1)-\tau-V_I\ge(<)0$.

Proof of Corollary 3

By Proposition 5, strategic substitutes is characterized by $\pi^m(1) - V_I > \tau$. This, in turn, implies that:

$$\pi^m(1) - V_I > \tau \Rightarrow \pi^m(1) - \frac{r\pi^m(0) + h(\hat{x}_I)\pi^m(1) + h(x_E)(\pi^m(1) - \tau) - \hat{x}_I}{h(\hat{x}_I) + h(x_E) + r} > \tau$$

$$\Rightarrow \frac{r(\pi^m(1) - \pi^m(0)) + h(x_E)\tau + \hat{x}_I}{h(\hat{x}_I) + h(x_E) + r} > \tau$$

$$\Rightarrow \frac{r(\pi^m(1) - \pi^m(0)) + \hat{x}_I}{h(\hat{x}_I) + r} > \tau = \frac{1}{2}\frac{r(\pi^m(1) - \pi^m(0)) + \tilde{x}_I}{\theta h(\tilde{x}_I) + r}$$

Notice that τ is at a minimum at $\tilde{x}_I$ (i.e., $\partial\tau(\tilde{x}_I)/\partial x_I = 0$ and $\partial^2\tau(x_I)/\partial x_I^2 > 0$ for all x_I) and $\theta \geq 1$ so that this inequality is always satisfied for the unconstrained case.

Figure One: Model Stages

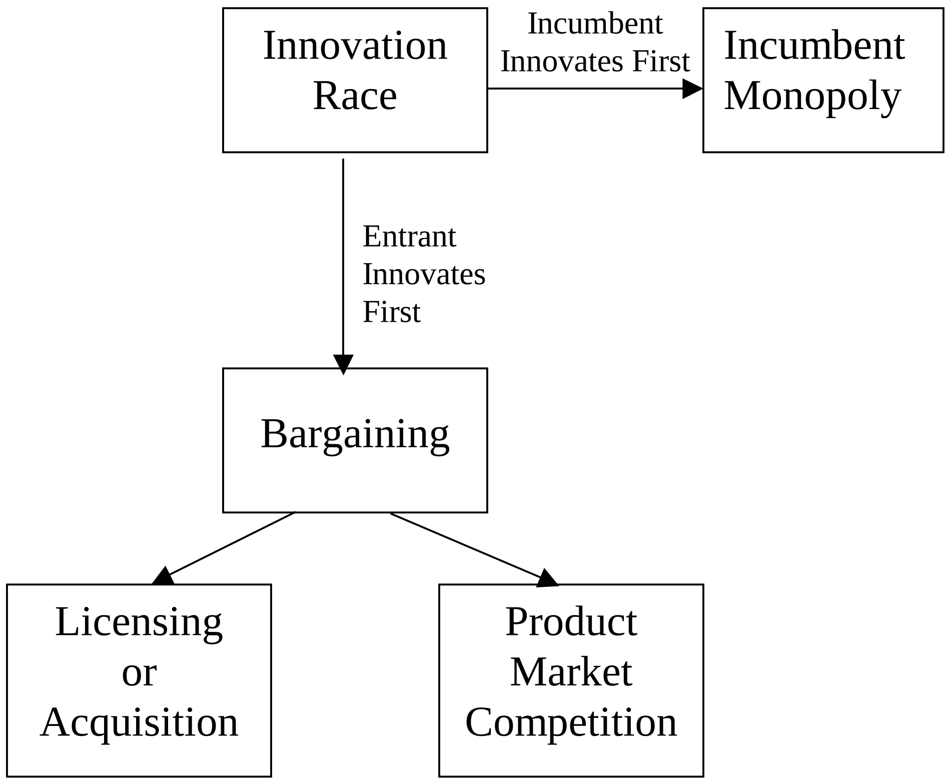
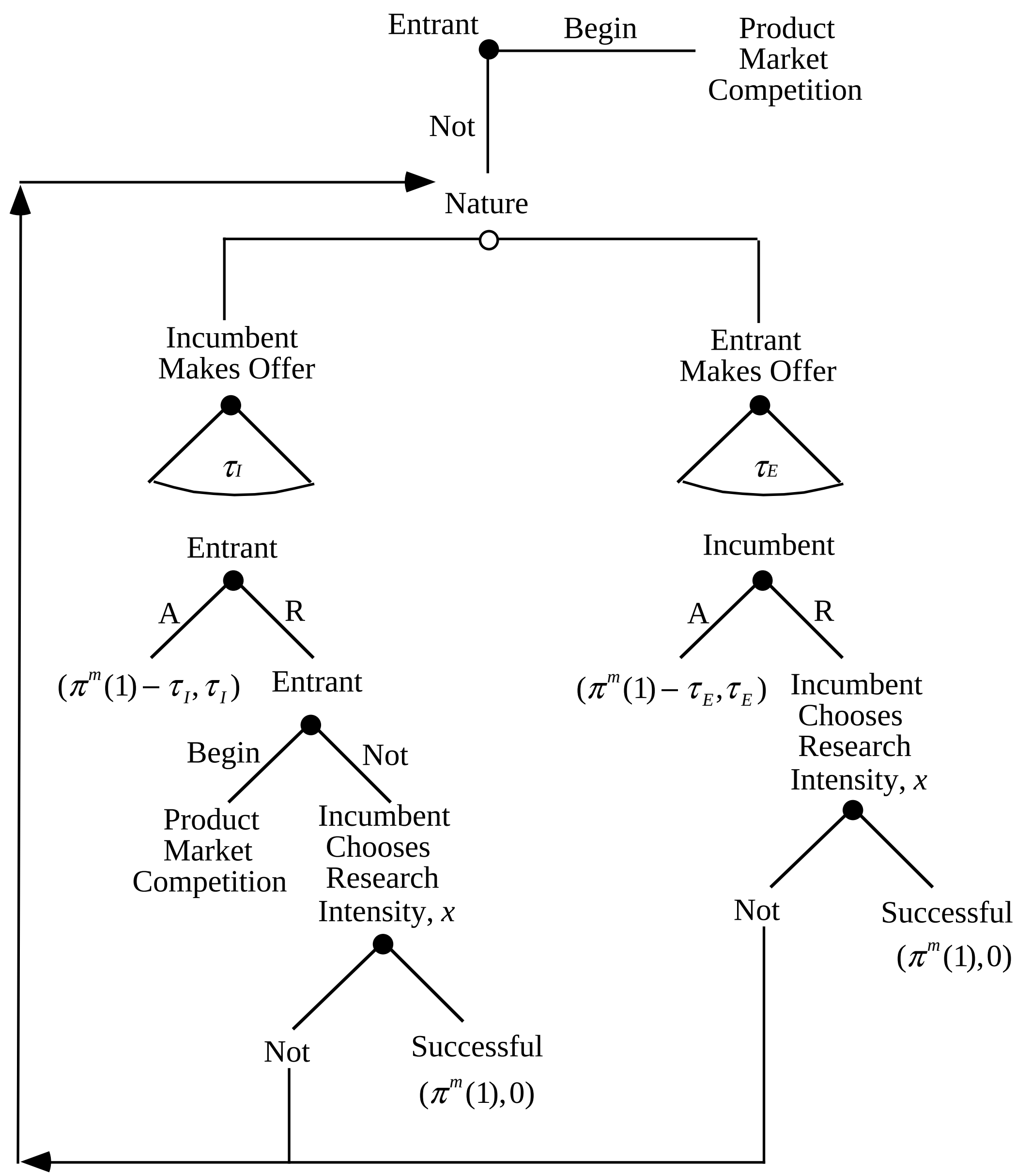


Figure Two: Bargaining Game



References

Aghion, P. and J. Tirole, 1994, "The Management of Innovation," *Quarterly Journal of Economics*, 109(4), 1185-1210.

Anton, J.J. and D.A. Yao, 1994, "Expropriation and Inventions: Appropriable Rents in the Absence of Property Rights," *American Economic Review*, 84(1), 190-209.

Anton, J.J. and D.A. Yao, 1995, "Start-ups, Spin-offs and Internal Projects," *Journal of Law, Economics and Organization*, 11(2), 362-378.

Arrow, K.J., 1962, "Economic Welfare and the Allocation of Resources for Invention," in R. Nelson, eds., *The Rate and Direction of Inventive Activity*, Princeton(NJ): Princeton University Press, 609-625.

Barese, P. and A. Brandenburger, 1992, "Race to Develop Synthetic Insulin," *Harvard Business School Case Series* (#9-191-121), Cambridge (MA): Harvard Business School Publishing.

Cockburn, I. and R. Henderson, 1994, "Racing to Invest? The Dynamics of Competition in Ethical Drug Discovery," *Journal of Economics and Management Strategy*, 3(3), 481-519.

Cohen, W. and D. Levinthal, 1990, "Absorptive Capacity: A New Perspective on Learning and Innovation," *Administrative Science Quarterly*, 35(1), 128-152.

Cusumano, M.A. and R.W. Selby, 1995, *Microsoft Secrets*, New York: Free Press.

de Fontenay, C. and J.S Gans, 1999, "Extending Monopoly Power Through Vertical Integration," *Working Paper* No. 99-2, Melbourne Business School.

Fudenberg, D., R.J. Gilbert, J.E. Stiglitz and J. Tirole, 1983, "Preemption, Leapfrogging and Competition in Patent Races," *European Economic Review*, 22, 3-31.

Gallini, N.T., 1984, "Deterrence by Market Sharing: A Strategic Incentive for Licensing," *American Economic Review*, 74(5), 931-941.

Gallini, N.T. and R.A. Winter, 1985, "Licensing in the Theory of Innovation," *RAND Journal of Economics*, 16(2), 237-252.

Gans, J.S., 1999, "A Strategic Theory of In-House Research and Development," in S. MacDonald and J. Nightingale, eds., *Information and Organization*, Amsterdam: Elsevier.

Gans, J.S. and S. Stern, 1999, "Competing Research Teams," *mimeo*., Melbourne.

Gilbert, R. and D. Newbery, 1982, "Preemptive Patenting and the Persistence of Monopoly," *American Economic Review*, 72(3), 514-526.

Green, J. and S. Scotchmer, 1995, "On the Division of Profit in Sequential Innovation," *RAND Journal of Economics*, 26(1), 20-33.

Hall, S.S., 1988, *Invisible Frontiers: The Race to Synthesize a Human Gene*, London: Sidgwick & Jackson.

Henderson, R., 1993, "Underinvestment and Incompetence as Responses to Radical Innovation: Evidence from the Photolithographic Alignment Equipment Industry," *RAND Journal of Economics*, 24(2), 248-270.

Holmstrom, B., 1989, "Agency Costs and Innovation," *Journal of Economic Behavior and Organization*, 12(3), 305-327.

Jones, C. and J.C. Williams, 1996, "Too Much of a Good Thing? The Economics of Investment in R&D," *Discussion Paper* No. 96-005, Department of Economics, Stanford University.

Katz, M.L. and C. Shapiro, 1987, "R&D Rivalry with Licensing or Imitation," *American Economic Review*, 77(3), 402-420.

Lee, T. and L.L. Wilde, 1980, "Market Structure and Innovation: A Reformulation," *Quarterly Journal of Economics*, 94, 429-436.

Lerner, J., 1997, "An Empirical Analysis of a Technology Race," *RAND Journal of Economics*, 28(3), 228-247.

Lerner, J. and R. Merges, 1998, "The Control of Technology Alliances: An Empirical Analysis of the Biotechnology Industry," *Journal of Industrial Economics*, 46(2): 125-156.

Levin, R., Klevorick, A., Nelson, R., and S. Winter, 1987, "Appropriating the Returns from Industrial Research and Development," *Brookings Papers on Economic Activity*, 3, 783-831.

Loury, G.C., 1979, "Market Structure and Innovation," *Quarterly Journal of Economics*, 93, 395-410.

Orsenigo, L., 1991, *The Emergence of Biotechnology: Institutions and Markets in Industrial Innovation*, London(GB): Pinter Publishers.

Osborne, M. and A. Rubinstein, 1990, *Bargaining and Markets*, New York: Random House.

Oster, S., 1990, *Modern Competitive Analysis*, 2nd ed., New York: Oxford University Press.

Pisano, G.P. and P.Y. Mang, 1993, "Collaborative Product Development and the Market for Know-How: Strategies and Structures in the Biotechnology Industry," *Research on Technological Innovation, Management and Policy*, 5, 109-136.

Rasmusen, E., 1988, "Entry for Buyout," *Journal of Industrial Economics*, 36(3), 281-99.

Reinganum, J.F., 1983, "Uncertain Innovation and the Persistence of Monopoly," *American Economic Review*, 73(4), 741-748.

Reinganum, J.F., 1989, "On the Timing of Innovation," in R. Schmalansee and R.D. Willig, eds., *Handbook of Industrial Organization*, v. 1, Amsterdam: North Holland, 849-908.

Rubinstein, A., 1982, "Perfect Equilibrium in a Bargaining Model," *Econometrica*, 50, 97-109.

Salant, S.W., 1984, "Preemptive Patenting and the Persistence of Monopoly: Comment," *American Economic Review*, 74(1), 247-250.

Shaked, A., 1994, "Opting Out: Bazaars versus 'Hi Tech' Markets," *Investigaciones Economicas*, 18(3), 421-432.

Stern, S., 1995, "Incentives and Focus in University and Industrial Research: The Case of Synthetic Insulin," in N. Rosenberg and A. Gelijns, eds., *Sources of Medical Technology: Universities and Industry*, Washington(DC): National Academy Press, 157-187.

Sutton, J., 1986, "Non-Cooperative Bargaining Theory: An Introduction," *Review of Economic Studies*, 53, 709-724.

Teece, D.J., 1987, "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing, and Public Policy," in D.J. Teece, ed., *The Competitive Challenge: Strategies for Industrial Innovation and Renewal*, Cambridge(MA): Ballinger, 185-220.

United States Department of Justice Antitrust Division, 1995, "Antitrust Guidelines for the Licensing of Intellectual Property," Washington: Government Printing Office.

Wolinsky, A., 1987, "Matching, Search and Bargaining," *Journal of Economic Theory*, 42, 311-333.