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

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

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We analyze the relationship between incumbency and innovative activity in the context of a model of technological competition in which 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 possibility of licensing leads to four key results. First, the unique equilibrium involves a technologically successful entrant licensing their innovation to the incumbent rather than entering the product market. Second, when intellectual property rights are weak, incumbents invest in R&D to achieve a strong bargaining position with technologically successful entrants. Third, incumbents research more intensively than entrants as long as (and only if) their "willingness-to-pay" for the innovation exceeds that of the entrant. Relative research intensity is unrelated to the pre-emption motives that were the primary concern of the previous literature. Finally, while the entrant always increases its research intensity in response to an increase in the incumbent's research intensity (strategic complementarity), the incumbent's response to an increase in entrant R&D depends on whether incremental rival research represents a positive or negative externality; when the incumbent's payoffs increase in the level of entrant R&D (as would occur when the licensing fee is relatively low), the incumbent considers entrant R&D an imperfect substitute for in-house research (resulting in strategic substitutability). *Journal of Economic Literature* Classification Numbers: Bargaining Theory (C78); Monopolization Strategies (L12); Vertical Integration (L22); R&D (O32).

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I. Introduction

How do entrants and incumbents differ in their incentives for innovative investment? How does technological change affect market structure? Since Schumpeter, these two questions have been taken as central to our understanding of the economics of technical change. Indeed, various models of technological competition (Gilbert and Newbery, 1982; Reinganum, 1983, 1989) have been used to highlight various aspects of these questions and to provide a framework for evaluating the public policy issues (e.g., antitrust or intellectual property) associated with their resolution.

In this paper, we consider these questions in the context of a model of technological competition in which successful entrants are able to license innovations to the incumbent (or, equivalently, to be acquired by the incumbent). By examining the strategic interactions between incumbent and entrant in both research and subsequent bargaining (over the license fee), this paper expands the range of strategies made available to a technologically successful firm; in so doing, we usefully uncouple the two questions above.

In particular, most previous formal research on technological competition has taken the relationship between market power and the incentives for innovation (the first question) to be intrinsically linked to the effect of innovation on subsequent market structure (the second question). That is, if an incumbent has the greater research incentives, then monopoly is likely to persist while for cases where an entrant has stronger incentives to do R&D, innovation will increase the level of product market competition over time. This supposed linkage arises from the structure of traditional models of technological competition (patent race models). In most patent race models, entrant and incumbent "race" to generate an innovation; when the entrant innovates first, entrant and incumbent then compete in the product market, each offering goods reflecting their intellectual property.

In contrast, our model includes the possibility of technology licensing in which competition for a patent is followed by cooperation between entrant and incumbent in maintaining monopoly rents in the product market. That such an arrangement ought to take place is natural given that both incumbent and entrant can both individually be made better off under monopoly relative to competition.[1] Of course, the potential for competition in the product market is not excluded; negotiations between the entrant and incumbent take place in the "shadow" of potential product market competition, determining the relative bargaining positions of each party.

By considering the possiblity of licensing and other cooperative arrangements, we hope to shed light on one of the primary way in which independent innovators (research-oriented firms without manufacturing or distribution assets) realize returns on innovative investment. For instance, the biotechnology industry is characterised by small research-focused firms who receive a large share (if not the entirety) of their revenues from the licensing agreements they hold with larger (more established) pharmaceutical and chemical companies. Indeed, in the "classic" patent race to develop synthetic insulin in

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[1] While we assume below (see footnote 10) that antitrust concerns prevent entrants who have begun production from merging with incumbents, we assume that antitrust law does not prevent an ex ante merger or licensing arrangement between the incumbent and independent research firm.

the late 1970s,[2] Genentech's return from successfully pre-empting other research teams did not come from successful product market entry but through its license with Eli Lilly, the incumbent producer of insulin. Moreover, Genentech purposefully sought to earn its return through a contractual solution.[3]

Even in industries where intellectual property protection is weaker, such as computer software, a substantial share of the innovations by "entrants" (independent innovators or firms which develop software outside their particular area of market experience) are licensed to (or acquired by) a firm with a substantial amount of incumbent market power in the segment for which the software is most useful. For example, in addition to its substantial in-house software development, Microsoft systematically acquires (or licenses from) independent software companies; as a result, Microsoft is among the largest acquirors of intellectual property in the world (Gawer, 1997; Cusumano and Selby, 1995).

Our model differs from the prior literature in three important ways. First, we allow for bargaining over the sale of successful innovations as an alternative to product market competition. Second, we allow the strength of intellectual property protection (i.e., the property rights over the innovation) to vary; under "weak" property rights, existing innovations can be worked around to develop products with similar functionality and economic value (Levin, et. al., 1987; Teece, 1987). Third, we allow for the possibility that the entrant faces a fixed cost of entering the product market (in the spirit of the complementary assets emphasized by Teece (1987)).

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[2] This case has been highlighted in Congressional testimony and is used to explain techological competition to business school students (Hall, 1988; Parese and Brandenburger, 1992; Stern, 1995).

Though these novel modelling elements expand the range of environments faced by and strategies available to incumbents and entrants, we are able to derive several strong implications summarized in four key results. First, under the usual assumptions of the patent race literature, licensing rather than competition in the product market is the unique equilibrium when the entrant successfully innovates prior to the incumbent firm. In short, anecdotes from biotechnology and software are the unique prediction of economic theory. From the viewpoint of models of technological competition which do not include ex-post information asymmetries between the incumbent and entrant, observations of entry into the product market, therefore, represent an economic puzzle (we extend our model to explore the role of information asymmetries in a preliminary way in Section V).

Our second key result arises from our treatment of the intellectual property associated with successful innovation. When property rights are "weak," an incumbent can (credibly) threaten to continue to research during negotiations with the entrant over a license. By being able to commit to do research when negotiations break down, incumbents are able to increase their bargaining power and to reduce the equilibrium license fee. In other words, our model suggests that incumbents have a *strategic reason 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, whether an incumbent or an entrant does more research depends on a simple, economically meaningful condition – which firm's expected payoff from their own successful innovation is higher. For the entrant, the

[3] Genentech executives conferred with Lilly on a regular basis and the licensing agreement was signed

expected payoff is the license fee; for the incumbent, the payoff is equal to the difference between their pre and post innovation monopoly profits. This simple *willingness to pay* condition (i.e., what is the maximum bid that either party would be willing to make to control the innovation immediately?) can be usefully contrasted with the conditions emphasized in the traditional patent race literature. In that literature, relative research intensity depends on a balancing of the incumbent's desire to pre-empt the entrant (Gilbert and Newbery, 1982) versus the relative disincentive to speed the arrival of new innovations which will, in part, simply *replace* the flow of profits associated with incumbency (Arrow, 1962; Reinganum, 1983). When licensing is possible, the pre-emption incentives are equalized (because the license fee earned by the entrant is simply subtracted from the payoffs of the incumbent), yielding our more simple condition. This condition allows us to analyse relative research intensities in a number of special cases. In particular, 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 will always research more intensively than an individual entrant.

The model also provides clear predictions about the nature of strategic interactions between incumbent and entrant. For entrants, the structure of strategic interaction resembles the traditional forces highlighted by the traditional patent race liteature. More precisely, entrants' incentives for research are always increasing in the level of incumbent research (the condition of strategic complementarity in R&D identified by Reinganum and others). In contrast, the incumbent's response to changes in

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only one day after the key experiment was verified.

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 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. On the other hand, when the licensing fee is high (e.g., when the entrant can credibly threaten to compete in the product market), the incumbent prefers continued racing to successful entrant innovation. In this case, incumbent research increases in response to an increase in entrant research, the condition of strategic complementarity analogous to the traditional literature.

Our model builds upon the suggestion by previous authors that the possibility of licensing might affect substantially the analysis of technological competition. For example, Gallini (1984) and Gallini and Winter (1985) demonstrate that incumbents have an ex ante incentive to license innovations to competitors so as to weaken rivals' incentives to engage in R&D in the future (see also Green and Scotchmer (1995) for a discussion of the difference between ex ante and ex post licensing in the context of sequential innovation). Closer to the concerns of the current paper, Salant (1984), in a critique of Gilbert and Newbery (1982), observes that licensing equalises the preemption motives of incumbents and entrants (a result which we exploit to derive relative research intenstities).[4] Finally, Katz and Shapiro (1987) examine how licensing between duopolists affects the speed of innovation, demonstrating that this question depends on a

[4] See also the response by Gilbert and Newbery (1984) and the discussion by Cave (1985).

comparison of each firm's preemption and willingness to pay[5] motives. While this previous literature identifies the link between the terms of licensing and the underlying incentives for innovation, our paper is the first to integrate licensing into a model of technological competition under uncertainty; the inclusion of the non-cooperative bargaining game (and allowing for the possibility of weak property rights) allows us to provide a much more complete treatment of the bargaining parameters as well as the parameters which determine the equilibrium research intensity.

The plan of the paper is as follows. In the next section, we introduce our basic model, building on the model of technological competition developed in Reinganum (1983). Section III then considers the non-cooperative bargaining game that results when an entrant innovates before an incumbent. We demonstrate that incumbents, in general, have an incentive to maintain an in-house research teams so as to reduce expected license fees paid to independent research teams. Using the results from the bargaining stage, we work backwards to consider the innovation race between an incumbent and an entrant and characterise their equilibrium research intensities (Section IV). We utilise these results to analyze the relative research intensities of incumbent and entrant, the nature of their R&D rivalry, and to re-consider Arrow's (1962) "replacement effect." In Section V, we briefly examine the consequences of information asymmetries, a potential source of failure to achieve the (efficient) licensing outcome. A final section concludes.

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[5] Katz and Shapiro (1987) termed this a "stand-alone" motive.

II. The Economic Environment

We consider R&D rivalry for a single innovation. More than one research team can pursue the new technology, and the intellectual property rights over the innovation are potentially weak. By this, we mean that the innovation can be pursued in distinct ways (limiting the scope of patent protection); each of these paths are assumed to be perfect substitutes in terms of the creation of economic value.

This treatment of intellectual property represents a break from the previous literature, which commonly assumes strong intellectual property rights (at least over each "generation" of a technology (Reinganum, 1989)). While the case of strong protection is easily accommodated within the model, our formulation allows us to analyze cases (such as in software or electronics) where innovations are not patentable (Anton and Yao, 1994), patents can be "worked around" to generate alternative technologies with identical economic characteristics (Levin, et. al., 1987; Teece, 1987), or patent litigation is prohibitively costly (Launjouw, 1994).

The technology for producing innovations takes a familiar form. When a research team, *i*, expends $x_i\Delta$ between time t and $t + \Delta$, then an innovation is generated in that time with probability $h(x_i)\Delta$.[6] $h(.)$ 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 $h(0) = 0 = \lim_{x_i \to \infty} h'(x_i)$. Throughout the paper, we assume that all teams are equally productive at R&D ($h(.)$ is

[6] 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).

common to all firms),[7] and that all agents have a common discount rate, $\delta \in [0,1)$. In analyzing the model, we will let $\delta = e^{-r\Delta}$ and look at continuous time solutions that result when $\Delta \to 0$.

We assume that each research team is either in-house or independent, ruling out intermediate contracting modes such as shop rights or limited exclusivity (see Aghion and Tirole, 1994; Lerner and Merges, 1997). Innovations which are produced by in-house teams are owned by the incumbent. As such, whenever an in-house team generates the innovation prior to the entrant, the incumbent can immediately exploit the innovation and earn $\pi^m(1)$, the present value of post-innovation monopoly profits (profits are denoted $\pi_i^y(a)$, the present value of *i*'s profits under market structure $y \in \{m, d\}$, where *a* = 0 when the incumbent does *not* have access to the innovation and *a* = 1 when the incumbent has control over the innovation).[8]

In contrast, independent research teams retain the property rights over their innovations; in order for the incumbent to exploit an independent research team's success, the incumbent must pay an endogenously determined license fee, τ. We make a clear distinction between an entrant's ability to undertake innovative activities and their ability to commercialize resulting innovations. If the entrant generates an innovation, it

[7] The model can be extended to examine the case where incumbent and entrant teams have different level of research productivity. One could consider the heterogeneous research capabilities emphasized by Henderson (1993), in which incumbents are more productive at competence-enhancing innovationn while entrants hold an advantage in realizing competence-destroying innovation. Alternatively, differences in research productivity could arise from the sensitivity of R&D productivity to equity ownership over the innovation (Aghion and Tirole, 1994). See Gans and Stern (1997).

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

has an option of entering production at a sunk cost, K.[9] An independent research team earns $\pi_E^d(a)$ after entering the product market; the entrant's duopoly profits are a decreasing function of the incumbent's intellectual property (notationally, $\pi_I^d(a)$ and $\pi_I^m(a)$ are the incumbent's duopoly and monopoly profits, respectively). Finally, if an independent research team enters production, that decision is assumed to be irreversible.[10]

We make three straightforward but substantive assumptions about the profit functions:

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

(A2) $\pi^m(1) \geq \pi_I^d(a) + \pi_E^d(a)$ for all a;

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

Generating and using the innovation improves monopoly profits (A1). Moreover, for all allocations of intellectual property, monopoly profits with the innovation are greater than the sum of duopoly profits (A2). Finally, under (A3), an entrant does not find it profitable to enter into production once the incumbent has control over the innovation (whether that control arises from licensing or from in-house research).

Since the incentives to invest in R&D arise from the expectation of rents from either licensing or entry into the product market, (A3) ensures that no team continues to research once the incumbent possesses the innovation. Taken together, (A1) - (A3) allow us to explore a model of technological competition where innovation can impact market

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

[10] Under the U.S. antitrust law, merger between competitors is much more difficult when they are engaging in product market competition. For example, the DOJ/FTC 1995 "Antitrust Guidelines for the Licensing of Intellectual Property," indicates that licensing will be opposed if it results in a potential entrant choosing not to become the productive competitor of an incumbent (p.55, Example 11).

structure (as would occur if an entrant innovates first and invests K) but need not do so (when the incumbent controls the innovation prior to an entrant investing K, product market structure will be preserved as a monopoly).

The basic timeline for the model is as follows. We take as exogenous the number (two) and ownership structure (in-house or indepedent) of research teams.[11] In stage 1, research teams choose their research intensities, x_i, and "race" to generate an innovation.[12] If the pioneer technology (the first technologically successful version of the innovation) is generated by an in-house team, the incumbent adopts that innovation and realises $\pi^m(1)$. In this event, by (A3), all teams stop researching. On the other hand, if the pioneer technology is generated by an independent team, stage 2 commences where the independent team and incumbent bargain over whether the innovation will be licensed and the level of the license fee.[13] The interesting feature of this bargaining game is that, given the possibility that property rights over the innovation may be weak, other research teams can potentially continue to research while the incumbent and entrant negotiate (a strategy which can affect the division of the rents among incumbent and entrant).[14] A breakdown in negotiations can be followed by entry into production by the entrant.

[11] One can separately consider solving for the equilibrium number of entrants. As discussed in Gans and Stern (1997), the main substantive conclusions of the current paper hold with an important caveat: in cases where the incumbent team performs at a higher research intensity than a single entrant, it could be the case that the incumbent performs less research than is performed by the independent research "sector."

[12] The model mirrors the framework developed by Reinganum (1983). As in the previous literature, each firms' chosen intensity is unobservable to the other (including whether the other firm is researching at all), which precludes the need to analyze "supergame" effects. The lack of observability of research effort is consistent with the assumptions of noncontractability made by Aghion and Tirole (1994). It is also implicit that the incumbent cannot integrate ex ante with the entrant (see Green and Scotchmer (1995) for a discussion of the difference between ex ante and ex post cooperation between the incumbent and entrant).

[13] In the traditional literature, Stage 2 would be composed of product market competition between the incumbent and entrant.

[14] In Sections III and IV, we generally assume that the productivity of R&D by a given research team, $h(.)$, is the same whether or not another team has successfully developed the innovation. However, within these sections, we briefly consider cases of "strong" intellectual property (i.e., $h(.) = 0$ for all levels of research

We will look for subgame perfect equilibria of this game by backwards induction. As such, we work backwards and first consider the solution to the bargaining game (Stage 2); we then use this analysis to characterize R&D investment and strategy during the innovation race (Stage 1).

III. Bargaining Over the License Fee

Bargaining over the license fee (Stage 2) commences when an independent research team generates an innovation prior to an in-house team. To characterize the properties of the equilibria of this bargaining process, we exploit the fact that the returns from innovation cannot be realized until production begins. Since delays in commercializing the innovation are costly, we usefully adapt the well-known bargaining framework in which negotiations take time and delay is costly (Rubinstein, 1982; Sutton, 1986). The bargaining solution thus depends on the relevant outside options of each of the parties, each parties' impatience, and the particular assumptions made about the extensive-form bargaining protocol.

While our main results are robust to different assumptions about the bargaining protocol (within the class of games summarized by Sutton (1986) and others), the potential presence of weak intellectual property rights requires us to develop the bargaining structure somewhat carefully. In particular, under weak intellectual property rights, additional R&D expenditures can yield a competing innovation with similar economic value. In the context of the bargaining model, this implies that the bargaining

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intensity after successful innovation by the other firm). In addition, Section V briefly considers the impact protocol must include a stage in which existing, but so far unsuccessful, research teams are able to invest in R&D and that these investments can, with some probability, change the relevant outside options of the incumbent (e.g., if the incumbent's in-house research team successfully generates the innovation during a period of bargaining disagreement, the incumbent will no longer be willing to pay the independent innovator a positive amount for the innovation).[15] Indeed, a central insight of this section is that the incumbent can (credibly) threaten to engage in R&D during periods of disagreement -- the strategic presence of an *in-house* R&D capability increases the share of the rents from innovation which accrues to the incumbent.

We analyze the case when an independent research team has successfully developed a version of the innovation and there is a single competing in-house research team. The extensive form for this bargaining process is depicted in Figure One. The bargaining protocol is symmetric; at the beginning of each time period, Nature randomly chooses the offering party (incumbent or entrant).[16] The chosen party makes an offer of a license fee, τ_i (where i is the offeror), for which the entrant will sell the innovation to the incumbent. If this offer is accepted, then the game ends and the entrant receives τ_i while the incumbent receives, $\pi^m(1)-\tau_i$. If this offer is rejected, the in-house team can be granted additional R&D resources. If this research is successful, the incumbent adopts the innovation (as the incumbent owns the outputs of in-house R&D at no cost) and the

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of learning across teams (which would increase $h'(.)$).

[15] Our bargain protocol is, therefore, very similar to Wolinsky (1987) who allows parties to search for attractive outside options during negotiations. Our analysis below differs from Wolinsky in that the incumbent can earn profits during negotiations and the entrant has an opportunity to exercise an outside option of starting-up production and competing directly with the incumbent.

game ends. In this event, the incumbent receives $\pi^m(1)$; given (A3), the entrant receives nothing. If no innovation is generated, the next period begins with Nature choosing another offeror. Finally, the entrant is allowed to begin production (a) prior to the commencement of negotiations and (b) following an offer by the incumbent.[17] As a simplifying assumption (which is not critical to any of our main analytical results), we have assumed that once the independent team has entered the product market, the incumbent and entrant do not collectively gain from licensing.[18]

The equilibrium bargaining solution depends on the outside options of each party, i.e., the (expected) payoffs that the incumbent and entrant, respectively, would receive in the absence of a successfully negotiated transfer of the innovation. We distinguish two cases. In the first, which we call the *credible entry* case, a technologically successful entrant can credibly threaten to compete with the incumbent in the product market (and to never license the innovation to the incumbent). In this case, the incumbent's expected payoff is dependent on the the continuing stream of in-house R&D investment, x_I:

$$V_I(x_I) = h(x_I)\Delta\pi_I^d(1) + (1 - h(x_I)\Delta)\big((1-\delta)\pi_I^d(0) + \delta V_I(x_I)\big) - x_I\Delta.$$

That is, given that we are considering a case where the entrant has already entered production, the incumbent expends R&D resources so as to earn the duopoly profits

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[16] This symmetrizes the extensive form game and thus, avoids problems of altering incentives to continue research depending upon whether the incumbent or the entrant is offering in the next period (Shaked, 1994).

[17] If the entrant could begin production at any time, there could be a multiplicity of subgame perfect equilibria with the entrant threatening to begin production if its own offers were not accepted. This would result in a continuum of equilibria and complicate the analysis of the ex ante innovation game below. See Osbourne and Rubinstein (1990, Chapter 3) and Shaked (1994) for a discussion of the multiplicity problem.

[18] The model straightforwardly accommodates the possibility of licensing after the independent team has entered the product market; however, 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 19 to 21). In addition, it should be emphasised again that entry is irreversible (see footnote 10).

feasible when it has control of the innovation. The assumed stationarity of the discovery process allows us to re-state the incumbent's dynamic programming problem (a stream of research choices) in terms of a simple choice of the period by period R&D investment decision of the incumbent, x_I, that maximises:

$$V_I(x_I) = \frac{(1-\delta)\pi_I^d(0) + h(x_I)\Delta\pi_I^d(1) - x_I\Delta}{1-\delta(1-h(x_I)\Delta)}$$

Let x_I^* be the research intensity that maximises $V_I(x_I)$ and $\overline{V}_I$ its maximised value. Given the incumbent's research intensity, the entrant's expected payoff is:

$$V_E(x_I^*) = h(x_I^*)\Delta\pi_E^d(1) + (1-h(x_I^*)\Delta)\big((1-\delta)\pi_E^d(0) + \delta V_E(x_I^*)\big)$$

$$\text{or } \overline{V}_E \equiv V_E(x_I^*) = \frac{(1-\delta)\pi_E^d(0) + h(x_I^*)\Delta\pi_E^d(1)}{1-\delta(1-h(x_I^*)\Delta)}.$$

The outside option of the entrant is determined by an (endogenously determined) period of favorable duopoly, $\pi_E^d(0)$, in which it is the sole supplier of goods which incorporate the superior technology; after the incumbent's in-house research team successfully generates a version of the innovation, the entrant's profits decline to $\pi_E^d(1)$.[19] While both the entrant and incumbent earn positive profits in this case, (A1) and (A2) imply that $\pi^m(1) > \overline{V}_I + \overline{V}_E - K$, so that there are mutual gains to be had from the entrant not beginning production and instead licensing the innovation to the incumbent.

We now turn to our second case, which we will call the *non-credible entry* case, in which the entrant cannot credibly threaten to enter the product market ($\overline{V}_E < K$) and so its outside option is zero. As in the credible entry case, the incumbent has the option of

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[19] Our assumption that the independent team does not have an incentive to license once it has entered the product market is simply the condition, $(\pi_I^d(1) + \pi_E^d(1) < \overline{V}_I + \overline{V}_E)$. When this condition is relaxed, the

continuing to invest in R&D and, in expected value, can earn the profits associated with pursuing the privately optimal amount of monopoly research.[20] Since the incumbent is impatient ($\delta < 1$), both the incumbent and independent can be made strictly better off by successful licensing ($\pi^m(1) > \overline{V}_I + 0$).

To characterize the solution to the bargaining game, we first analyze the level of R&D that the incumbent will be able to credibly threaten to undertake during periods of disagreement. Following a rejection, the incumbent 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:

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

The incumbent's investment induces some probability of generating the innovation in-house and realizing $\pi^m(1)$; when R&D is unsuccessful, the incumbent earns the old monopoly profits and expects to reach a licensing agreement in the following period. The incumbent thus chooses a research intensity, $\tilde{x}_I$, which maximise this payoff according to the following first order condition:

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

$\tilde{x}_I$ is increasing in $\pi^m(1)$ and $h'(x_I)$ and decreasing in $\pi^m(0)$, holding τ_E and τ_I constant; also, $\tilde{x}_I$ is unique given the global concavity of $h(.)$. With this solution, 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:

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relevant outside options associated with entering the product market are those that would result when the incumbent and entrant bargain over a horizontal license as duopolists.

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 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:*

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

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

The proof (in the appendix) proceeds along the lines of Wolinsky (1987, Proposition 1). 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 weak property rights and commercialization costs enhance the bargaining position of the incumbent, gains from licensing are present (and achievable) even if commercialization is costless and intellectual property rights are strong.

To see this more clearly, suppose intellectual property rights are strong and so the incumbent cannot threaten to do R&D (e.g., $h(.)$ falls to zero for all x_I after the entrant innovates). This constraint on the incumbent 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

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[20] That is, the incumbent's outside option is: $\overline{V}_I=\max_{x_I}\dfrac{(1-\delta)\pi_I^m(0)+h(x_I)\Delta\pi_I^m(1)-x_I\Delta}{1-\delta(1-h(x_I)\Delta)}$.

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

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

where $\tilde{x}_I(m)$ and $\tilde{x}_I(d)$ are the incumbent's choices of research intensity during negotiations when it is a monopolist and duopolist respectively. Thus, the feasbility 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).

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. However, under our assumption of weak property rights and the presence of an in-house team, continued R&D during negotiations raises the possibility that the incumbent could credibly discontinue negotiations and appropriate the entirety of the rents from innovation; this threat reduces the equilibrium license fee. Incumbent firms therefore have a *purely strategic* 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.[22]

Proposition 1 also makes clear the difference between what we have been calling the credible and non-credible entry cases. When entry is not credible, the license fee is always what we term *unconstrained* (by the possibility of entry). In this case the bargaining solution depends solely on impatience (which is implicitly determined by the threat of in-house R&D success) and bargaining position. However, the length of time between negotiating rounds is infintesimal and so neither party is able to earn a premium by being chosen to be the offeror (the other party will refuse offers less favorable than the equilibrium offer and wait until their own turn to be the offeror). In contrast, when the entrant can credibly threaten to enter production, the equilibrium licensing fee may be *constrained* to be at least as high as this outside option of the entrant. Indeed, since the

[22] This strategic effect can be contrasted with Cohen and Levinthal's bounded rationality justification -- *absorptive capacity* -- for the development of an R&D capability (Cohen and Levinthal, 1990). The strategic advantage to in-house R&D is explored further in Gans and Stern (1997) where we construct a multi-player bargaining game with a single incumbent and many potential entrants and demonstrate that the in-house research team has a greater incentive to research during negotiations than independent teams without innovations. de Fontenay (1997) obtains a similar effect in a model of vertical integration. In her model, integration allows a monopsonist to prevent unfavourable renegotiation with some of its suppliers, thus, giving it leverage over any independent suppliers. See also Gans (1997).

exercise of this outside option is an irreversible act on the part of the entrant, the equilibrium fee will shift up to precisely the value of this outside option (Osborne and Rubinstein, 1990, Proposition 3.5, p.56); as a result, the license fee is the maximum of the unconstrained solution and entrant's outside option.

Finally, it is useful to note that when innovation has no value to the incumbent per se, $\pi^m(1) = \pi^m(0)$ (a common assumption in the traditional patent race literature), then $\tau = 0$ unless entry is credible ($\overline{V}_E \geq K$),[23] in which case the incumbent is willing to pay purely for the maintenance of a monopoly market structure.[24]

To characterize the comparative statics of this bargaining solution, first note 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 and this has the effect of reducing the share of the rents from innovation which accrue to the independent. These monotone relationships among the endogenous variables allow us to prove the following comparative statics on the licensing fee:

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 $\pi^m(0)$, $\pi_I^d(0)$ and K.*

As mentioned above, changes in the exogenous parameters of the model do not change the qualitative outcome of licensing but only serve to change the price at which the licensing agreement is exercised. On the part of the entrant, bargaining power is determined by the sunk commercialization costs versus the duopoly profits (note that in

[23] This follows since $h(.)$ is quasi-concave, implying $h'(x_I)x_I < 2(h(x_I)+r)$, for all x_I.

[24] (A3) ensures that the incumbent will pay for monopoly only once; further entrants are deterred (see Rasmusen (1988) for a discussion of the conditions under which monopolists will pay to deter entry).

the unconstrained case, the licensing fee is insensitive to small changes in the duopoly profits parameters). The incumbent, on the other hand, can be "patient" when the incremental profits to be gained from adopting the innovation ($\pi^m(1)-\pi^m(0)$) are small and the entrant cannot credibly threaten duopoly. In the context of the bargaining game, the effect of the current stream of monopoly profits (Arrow's "replacement effect") is to allow the incumbent to acquire competitive technologies at a reduced price (we will discuss the role of the "replacement effect" on the incentives to engage in R&D in the next section).

IV. The Innovation Race

This section poses and answers three questions which lie at the heart of 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)? and (c) How is the level of R&D investment affected by pre-innovation monopoly profits? We answer these questions in the context of the canonical model of technological competition (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 technology licensing on R&D investment.

Our discussion begins by specifying the payoff functions of the incumbent and entrant. 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). The expected payoffs for entrant and incumbent become, respectively:

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

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

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

where the equality comes from the assumed stationarity of the research technology (also known as *memoryless technology*) allowing us to solve the dynamic programming problem (a stream of research choices) as the solution $(\hat{x}_I,\hat{x}_E)$ to the period by period R&D investment game. The asymmetry between the incumbent and entrant payoffs functions (at the heart of the rest of our analysis) arise from the fact that (1) the incumbent receives $\pi^m(0)$ until the innovation is brought into the market, (2) the entrant's payoff from their own successful innovation (τ) is different than the incumbent's ($\pi^m(1)-\pi^m(0)$), and (3) the expectation of licensing in the case of successful entrant innovation implies that the incumbent'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 the incumbent's and entrant's first order conditions, respectively. Our conditions on *h*(.) guarantee that the solution to these equations are interior. Both the incumbent and the entrant 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. This 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. We can thus turn to the questions posed at the start of this section by analyzing these equilibrium equations.

(a) Does the incumbent or the entrant do more R&D?[25]

Our analysis focuses on a comparison of the left hand side of the equilibrium equations in Proposition 3, which give the two components of the marginal benefit to current research: an interaction with the probability that the other firm 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).[26]

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. The entrant receives no return when they lose, so this incentive is simply τ. The

[25] More generally, what determines the relative R&D intensity of incumbent and entrant? As we show, isolating who does more can be done without explicitly examining whether entrant and incumbent research are strategic substitutes or complements (as would be required to analyze this more general question and addressed in the next sub-section).

[26] 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.

incumbent receives $\pi^m(1)$ if they win and $\pi^m(1)-\tau$ otherwise, yielding a pre-emption incentive of τ as well. Thus, in a model of technological competition with licensing, the pre-emption incentives are equal.[27]

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 in the absence of any R&D rivalry. By increasing research intensity, these rents can be earned sooner. For the entrant, this means earning the license fee τ, while for the incumbent, succcessful innovation means that they earn $\pi^m(1)$ 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 the incumbent and entrant equilibrium conditions. As such, it holds the key to the relative research intensities of incumbent and entrant.

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

The simple condition here (a comparison of the WTP incentives) allows us to characterize how the determinants of τ (see Proposition 2) affect the underlying incentives to research. More precisely, exogenous factors in the second stage which impact the first-stage R&D choices only through their influence on τ affect relative

[27] 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 the incumbent's pre-emption incentives always exceed those of the entrant (Gilbert and Newbery, 1982). In the absence of licensing and under strong intellectual property, the incumbent's pre-emption incentive is $\pi^m(1)-\pi^d_I(0)$ while the entrant's incentive to innovate first is $\pi^d_E(0)-K$. Even when $K = 0$, the incumbent's incentive exceeds the entrant's when licensing is prohibited (by (A2) and (A3)).

research intensities according to the condition in Proposition 2.[28] 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. We can, therefore, utilize Propositions 1 and 2, along with Proposition 4, to characterize a number of useful cases, comparing our results to prior work on technological competition.

In Section III, we found that the an important determinant of the licensing fee is whether or not the fee was constrained by the entrant's outside option. This condition also allows us to characterize relative research intensity:

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

As highlighted by Proposition 1, the unconstrained case arises whenever K is sufficently high, in particular, when it makes product market entry non-credible. In that case, the upper bound on τ is $\frac{1}{2}\left(\pi^m(1) - \pi^m(0)\right)$ and this is clearly less than the incumbent's WTP. An empirical implication of this is that innovations are more likely to be generated by the incumbent when the costs of entering product market competition are sufficiently high.

In contrast, when innovations are drastic ($\pi^m(1) = \pi_E^d(0)$ and $\pi_I^d(0) = 0$), there are several forces reinforcing the relative research intensity of the entrant. While in the previous literature (Reinganum, 1983), drasticness reduces the asymmetry between the incumbent and entrant in terms of their pre-emption incentives, here it serves to raise the entrant's WTP relative to that of the incumbent. As well, to the extent that "drastic" innovation renders obsolete the prior product market assets of the incumbent (Teece, 1987), K (the difference between the entrant's and the incumbent's fixed cost in

[28] This includes K, $\pi_E^d(0)$ and $\pi_I^d(0)$.

introducing the innovation) will be low. This allows us to make an unambiguous prediction when intellectual property protection is strong:

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

This result, though similar to the previous literature, also suggests some checks on prior findings. In particular, when the entrant faces idiosyncratic costs to product market entry or the incumbent has the potential for continuing R&D, then one cannot make an unambiguous prediction.

Corollaries 1 and 2 depend on comparative statics implied by a comparison of the equilibrium equations along with the comparative statics on τ in Proposition 2. In order to characterize the comparative statics on exogenous parameters which directly impact on the equilibrium equations, we must first examine the nature of the strategic interaction between the incumbent and the entrant, the task to which we now turn.

(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.[29] 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 (Henderson and Cockburn, 1995; Lerner, 1997), macroeconomic modelling of technological change (Jones and Williams, 1996) and public policy (Green

[29] That is, as one agent raises its research intensity, this makes it optimal for the other agent to raise their R&D intensity in response (Reinganum, 1983). As in the previous literature on technological competition (e.g., 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.

and Scotchmer, 1995). The key to this prediction arises because, in traditional models of technological competition, the expected profits of each firm are decreasing in rival research effort. 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. When a rival increases their research intensity, this impacts only V_i; since rival research intensity lowers V_i in the traditional literature (i.e., increasing the marginal benefit to own research), research efforts are strategic complements.

In our model, it is still the case that the entrant's expected payoff is decreasing in incumbent research effort.[30] This is because successful innovation by the incumbent cuts the entrant off from any rents. Therefore, the entrant will react to increased effort by the incumbent by escalating their own research. For the incumbent, however, successful innovation by the entrant still allows it to earn the monopoly profits associated with the innovation minus the bargained-upon licensing fee. As a result, it is possible that entrant research effort could have a positive impact on the incumbent's expected payoff; the incumbent might prefer the entrant to research more.

How might greater research effort on the part of the entrant serve to increase the incumbent's expected payoff and, hence, cause them to lower their own effort? Observe that:

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

[30] Note that $\frac{\partial^2 V_E}{\partial x_E \partial x_I} = \frac{h'(x_I)}{h(x_E)+h(x_I)+r}\left(\frac{h'(x_E)(\tau - V_E) - 1}{h(x_E)+h(x_I)+r} - \frac{\partial V_E}{\partial x_I}\right) \geq 0$, where the first component of the bracketed term is zero by the entrant's first order condition.

Higher entrant research increases the probability that the incumbent will earn $\pi^m(1)-\tau$ as opposed to its pre-innovation expected payoff, $V_I(x_I, x_E)$, in the future. As result, when the license fee is relatively low, the incumbent might prefer entrant innovation now as opposed to continuing the innovation race in the future. In this case, entrant research is an imperfect substitute for in-house R&D causing the incumbent to accommodate increased entrant research intensity by reducing its own research effort. Our main finding can thus 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* $V_I(x_I, x_E) \leq \pi^m(1)-\tau$.

This condition allows us to characterize a number of interesting 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), the incumbent is able to retain a sufficient level of bargaining power to ensure that they are better off when the entrant innovates than when neither agent innovates.

Corollary 3. *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 the incumbent behaves according to strategic substitutability.[31] 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.

[31] 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.

In contrast, when 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 the incumbent is decreasing in the level of entrant research.

Corollary 4. *If the innovation is drastic, $K = 0$ and intellectual property rights are strong, then the incumbent's research intensity is a strategic complement for entrant research.*

These two extreme cases 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 increases in the R&D of that competitor will be increasing (and the converse also holds).

(c) How is the level of R&D investment affected by pre-innovation monopoly profits?

Since Arrow (1962), several authors have attempted to characterize how pre-innovation incumbent profits affect the incentives for innovative investment (the so-called "replacement effect"). Arrow, of course, argued that the existence of pre-innovation monopoly earnings lowers the incumbent's incentive to innovate relative to a situation in which there is competition in the pre-innovation market (Arrow, 1962). Like all models of technological competition, our model captures the original Arrow notion that was discussed in an environment without technological rivalry: that is, $\pi^m(0)$ has a negative impact on the incumbent's WTP incentive. In addition, however, $\pi^m(0)$ also influences τ (and therefore the incumbent's pre-emption incentive) in two distinct ways. First, as $\pi^m(0)$ increases, lengthy negotiations are less costly, making the incumbent more patient. As well, its incentive to engage in strategic research during negotiations is lower, reducing the incumbent's bargaining power. From Proposition 2, we known that the former effect outweighs the latter, so that:

$$\frac{\partial^2 V_I}{\partial x_I \partial \pi^m(0)} = -h'(x_I)\frac{r - h(x_E)\frac{d\tau}{d\pi^m(0)}}{(r+h(x_I)+h(x_E))^2} \leq 0.$$

The additional bargaining effects present in our model reinforce the replacement effect discussed in the traditional literature. However, this does not allow us to conclude that an increase in pre-innovation monopoly profits would result in a reduction in the equilibrium level of incumbent research. This is because in our model, the level of pre-innovation profits also influence the entrant's incentives directly by entering the licensing fee, τ, in the unconstrained case. For the entrant, any increase in the incumbent's bargaining power is a reduction in its own incentives to innovate, i.e., $\partial^2 V_E / \partial x_E \partial \pi^m(0) \leq 0$. If the research choices of incumbent and entrant are strategic complements (as in the traditional literature), these two conditions will imply that an increase in pre-innovation monopoly profits will lead to a decrease in both incumbent and entrant research. However, in the unconstrained case (precisely when pre-innovation profits are directly affecting the entrant's incentives), incumbent research is a strategic substitute with entrant research.

This leads us to conclude that while $\hat{x}_I$ may be increasing or decreasing in $\pi^m(0)$, $\hat{x}_E$ is non-decreasing in $\pi^m(0)$. We can sign unambiguously only the entrant's research effort; the incumbent's sensitivity to the entrant's research level mitigates against an unambiguous finding in this case. More positively, this conclusion highlights that the "replacement effect" can be usefully interpreted as an effect of incumbency on the overall research sector and not necessarily on the observed research effort of incumbents themselves.

To see this more clearly, it is useful to analyze how the overall level of research investment changes with the level of pre-innovation monopoly profits.[32] Since the incumbent is in the strategic substitutes case, we need to provide a "bound" on the sensitivity of incumbent research to the level of entrant research:[33]

$$\text{(A4)} \quad -h'(x_I)\frac{dx_I}{dh(x_E)} < 1;$$

This assumptions guarantees that the response of the incumbent to a change in the research effort of the entrant is of a smaller order of magnitude. (A4) implies that the slope of the incumbent's reaction curve is not less than -1 (i.e., it is not too steeply negative) and is satisfied whenever *h*(.) is sufficiently concave.[34] Under (A4), we can demonstrate the following:

Proposition 6. *Assume (A1) - (A4). Then* $\hat{x}_I + \hat{x}_E$ *is non-increasing in* $\pi^m(0)$.

Therefore, an increase in pre-innovation monopoly rents leads to a lower level of overall research effort and hence, a later expected date for the innovation be generated. Note that when incumbent research is a strategic substitute with entrant research, even though the direct effect of an increase in $\pi^m(0)$ is to shift each firm's reaction curve inwards, the indirect effect of this is a rise in incumbent research effort. Under (A4), this indirect effect is outweighed by the reduction in the entrant's equilibrium effort.

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[32] We conduct (local) comparative static analysis on the total ($\hat{x}_I + \hat{x}_E$) level of research effort.

[33] See Reinganum (1989) for a discussion of this condition (which originates with Loury (1979)).

[34] It is also satisfied when τ is constrained, in which case pre-innovation monopoly profits have no direct negative effect on entrant research.

V. Information Asymmetries and Expropriation

In the previous two sections, we derived the principal implications of a model of technological competition which accommodates the potential for technology licensing as an alternative to product market competition. We now extend the model to highlight potential reasons why an entrant may not take advantage of contracting solutions. While one could consider several potential sources of contractual failure,[35] we concentrate here on the potential role of information asymmetry.[36]

So far, we have generally assumed that incumbent research productivity is unaffected by successful innovation by the entrant. Suppose now that the incumbent's research productivity in this event is described by a function, $\tilde{h}(x_i)$. We focus in this section on the implications of learning whereby $\tilde{h}(x_I) > h(x_I)$ and $\tilde{h}'(x_I) \geq h'(x_I)$ for all x_I.[37] We distinguish between learning that takes place as a result of (a) the fact of entrant innovation; (b) the commencement of negotiations over the sale of the innovation; or (c) the introduction of the product into the market in the absence of negotiations. While a full analysis would consider each case (and awaits future research), we highlight one particularly interesting case — where there is no learning under (a) and (c) (i.e, no "reverse engineering") but the act of bargaining (case (b)) involves information disclosure which raises the productivity of incumbent research.

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[35] For example, there could be a preference for "empire building" on the part of entrants or the potential for sequential innovation which relies on learning-by-doing in the manufacturing process.

[36] In so doing, we follow the tradition of Arrow (1962). While much of the technological competition literature focuses on the "replacement effect" identified in the penultimate section of Arrow (1962), the bulk of Arrow's seminal work focuses instead on the special nature of innovation as an "information good" and the implications of allocative failure in markets for information for patterns in the use of knowledge and the incentives to create knowledge. See also Anton and Yao (1994).

[37] Thus, learning across teams is the flip side of strong intellectual property protection.

We need to distinguish between the unconstrained and constrained cases.[38] In the unconstrained case, information disclosure serves to reduce the equilibrium licensing fee. While this reduces the entrant's ex ante research incentives, it does not alter the equilibrium outcome that the entrant licenses to the incumbent.

The constrained case is more subtle. Recall that the entrant's payoff when they enter the product market in lieu of negotation is $\overline{V}_E - K$. In contrast, the bargaining solution under proposition 1 will be $\tilde{V}_E - K$, where $\tilde{V}_E$ is the expected value of entrant profits if negotations break down and the incumbent is able to conduct his own research with the "improved" research function, $\tilde{h}(x_I)$. Under our assumptions, $\tilde{V}_E < \overline{V}_E$. At first blush, this suggests a "knife-edge" result — even with small information asymmetries, the entrant will choose to forego negotiations. However, the incumbent has an incentive to eliminate this wedge so as to encourage negotiation. For example, the incumbent can offer a "negotiation bonus" — an upfront payment of $\overline{V}_E - \tilde{V}_E$ which the entrant receives even in the case of negotiation breakdown.[39] Alternatively, the entrant could offer to exchange information which reduces K, the cost of product market entry, to $\tilde{K} = \overline{V}_E - \tilde{V}_E$ (i.e., the incumbent can endogenously choose to reduce the entrant's cost of entering the product market in order to encourage negotiations). Both of these potential solutions require the incumbent to offer a quid pro quo with the entrant — to offer a sunk inducement in order for the entrant to be willing to enter a negotation stage in which their outside options are reduced.

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[38] Changes in the level of disclosure can affect the "regime" itself; we abstract away from this possibility.
[39] Of course, this assumes that the incumbent (and entrant) have information regarding the monetary effect of information disclosure. However, even if there were uncertainty over this, the knife edge result is eliminated when some form of an up-front payment is feasible.

This disclosure problem can additionally impact the level of research intensity in the innovation race. In the unconstrained case, the reduced licensing fee associated with disclosure reduces the underlying incentive of entrants to innovate leading to an increase in the research intensity of the incumbent (an implication of strategic substituability, see Corollary 3). For the constrained case, however, the presence of a credible threat by the entrant to earn $\overline{V}_E - K$ ensures that, in any negotiated equilibrium, the incumbent cannot take advantage of the information disclosure; since the returns from innovation by the entrant are kept constant in order to encourage negotation, the entrant and the incumbent's underlying incentives to innovate remain constant.[40]

This section only hints at the implications of information asymmetry on the equilibrium licensing fee and on the underlying incentive to innovate. Our analysis suggests, however, that a fruitful area for additional research is to explore how information asymmetry interacts with different contracting possibilities (such as the potential for a bargaining inducement) which are then exercised (or not) in the shadow of potential product market competition.

VI. Concluding Thoughts

In conclusion, we return to the Schumpeterian questions which motivated this paper.

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[40] This is a very similar conclusion to that reached by Anton and Yao (1994). They demonstrated that independent researchers with weak property rights can earn innovation rents from licensing when there are several potential users of the innovation in the product market, which is analogous to the credible entry case considered here.

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 market or through contracting. 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 marketplace. 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 which 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. Of course, several other factors impinge on the relative innovation incentives of incumbent and entrant (differences in research productivity come to mind). However, when licensing is an option, these auxiliary factors will simply affect the particular price at which the license is realized. The qualitative difference between the means by which an incumbent and entrant earn returns on innovation (contracts versus markets) 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 articulated. Whereas previous research on technological competition essentially assumes the procompetitive effects of successful entrant innovation, this paper analyzes this question and finds that 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 bargaining protocol we analyze or the particular structure of the game we propose to analyze the licensing fee, the main result is robust – under the assumptions of the prior literature, innovation has no effect on observed market structure. The analysis in the penultimate section of this paper suggests that licensing solutions could be undermined in the presence of knowledge disclosure problems which preclude achievement of the first-best (a possibility empahasized by Arrow (1962)). Indeed, given the present analysis, we speculate that observing competition in markets where innovation is important may be suggestive of an earlier market failure – in the "market for ideas."

Appendix

Proof of Proposition 1:

The proof proceeds in steps. First, we look at the game assuming that the entrant does not wish to begin production at any stage. Then we turn to consider the full game in which entry is an option for the entrant.

Step One: Suppose first that the entrant does not wish to begin production either before or during negotiations. Following Wolinsky (1987), given (A1), the subgame equilibrium is characterised by the following equations:

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

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

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

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

Solving these equations gives:

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

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

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

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

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:

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

Step Two: Suppose now that the entrant might enter into production. Given (A2), it is not in the interests of either party for the entrant to begin production prior to negotiations. This option means that the entrant 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 the incumbent'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. $\text{sgn}\frac{d\tau}{d\theta} = \text{sgn}\frac{\partial\tau}{\partial\theta}$

PROOF: Note first that:

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

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

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

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

Thus, at the equilibrium $\tilde{x}_I$ changes in any parameter which 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.

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

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

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.,

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

This simplies 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 characterised by $\pi^m(1) - V_I > \tau$. This, in turn, implies that:

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

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

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

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) so that this inequality is always satisfied for the unconstrained case.

Proof of Proposition 6

Observe that:

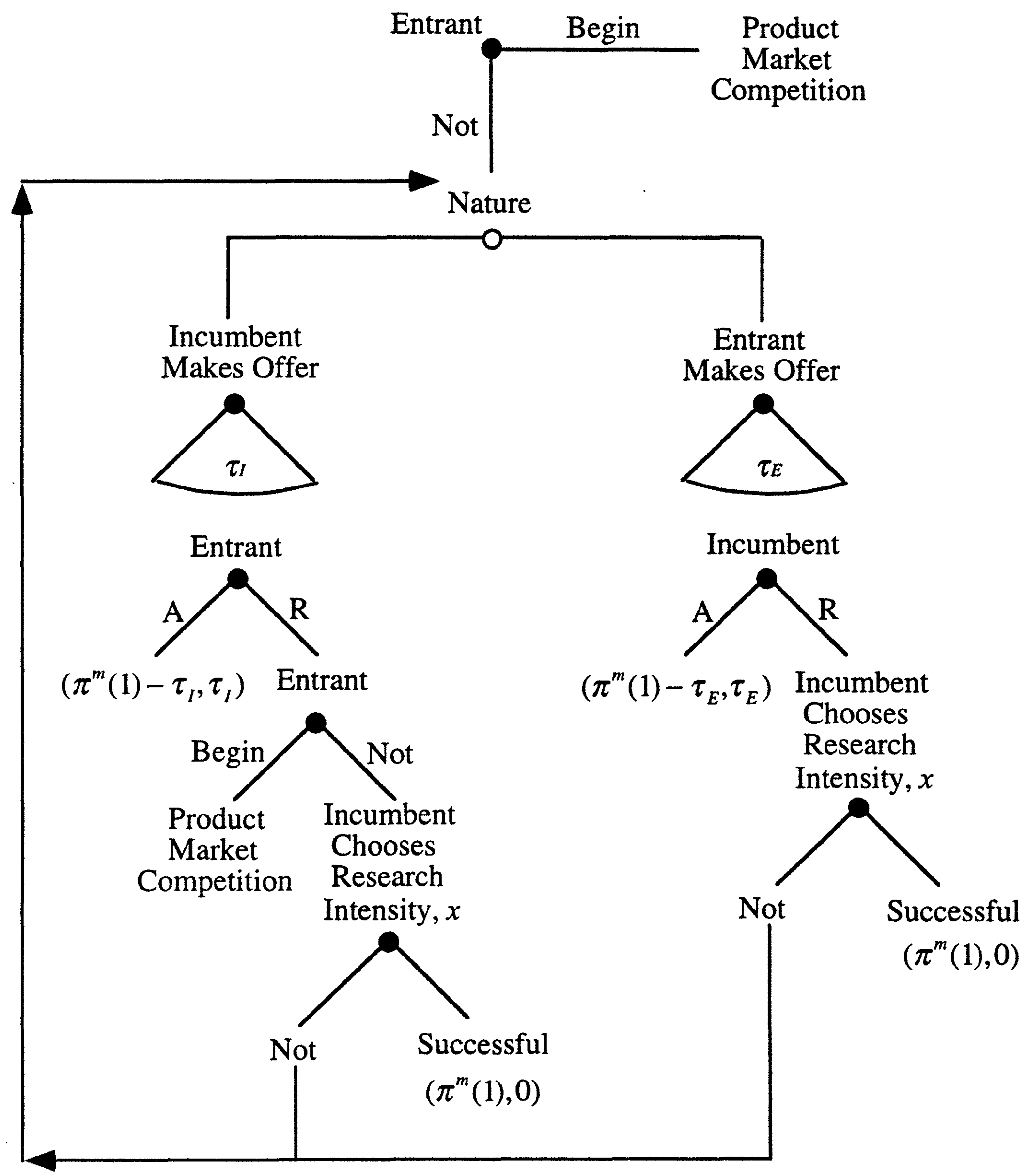
$$\frac{d(\hat{x}_I + \hat{x}_E)}{d\pi^m(0)} = \frac{d\hat{x}_I}{d\pi^m(0)} + \frac{d\hat{x}_E}{d\pi^m(0)} = \frac{\partial\hat{x}_I}{\partial\pi^m(0)} + \frac{\partial\hat{x}_I}{\partial x_E}\frac{\partial\hat{x}_E}{\partial\pi^m(0)} + \frac{\partial\hat{x}_E}{\partial\pi^m(0)} + \frac{\partial\hat{x}_E}{\partial x_I}\frac{\partial\hat{x}_I}{\partial\pi^m(0)}$$

This being non-positive implies that:

$$\frac{\partial\hat{x}_I}{\partial\pi^m(0)}\left(1 + \frac{\partial\hat{x}_E}{\partial x_I}\right) \leq -\frac{\partial\hat{x}_E}{\partial\pi^m(0)}\left(1 + \frac{\partial\hat{x}_I}{\partial x_E}\right)$$

As $\partial\hat{x}_I/\partial\pi^m(0)$ and $\partial\hat{x}_E/\partial\pi^m(0)$ are negative while $\partial\hat{x}_E/\partial x_I$ is positive, a sufficient condition for this to be true is that $\partial\hat{x}_I/\partial x_E > -1$ which is implied by (A4).

Figure One: Bargaining Game



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