Strategic Information Disclosure: The Case of Pending Patents

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Abstract

In many jurisdictions, the existence and contents of patent applications are unknown to third parties until the application is published by the patent office at least 18 months after the initial filing. In contrast to other features of the patent system, this publication lag has received little analytical attention. The patent applicant can expedite public awareness of the existing application and the respective technology by announcing the patent application before its automatic publication. In our model, the applicant balances a negative effect of disclosure on its informational advantage in the short run (*value of secrecy*) with a positive long-run effect stemming from potential deterrence of a rival's R&D (*value of deterring innovation*). We give conditions under which announcing the pending patent deters a rival's innovation. We show that, in equilibrium, the applicant's decision to announce and the rival's decision to innovate are non-monotonic in the strength of the application and the strength of the patent. We present evidence supporting core predictions of our model by identifying press releases, one channel for disclosing business information, that announce nothing but the recent filing of patent applications. Using a technique suggested in the corporate finance literature, we estimate a measure of the nature of competition for all major NAICS codes. In doing so, we are the first to provide broad evidence supporting the prediction dating back to Gal-Or (1986) that cost disclosure depends on the nature of competition in an industry.

Key words: competition, information disclosure, innovation, IP management, patenting, partial disclosure, pending patents, R&D, secrecy, trade secrets.

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1 Introduction

In the United States and many other jurisdictions, pending patent applications are typically published 18 months after the initial filing. This practice has been criticized (Modigliani, ????) because it puts inventors' intellectual property into the public realm before a final grant decision about the patent has been made,[1] affording competitors' more time to engineer around the invention (Bessen and Meurer, 2006) or depriving the inventors of using other means of intellectual property protection (e.g., trade secrets). Recent empirical evidence, however, indicates that inventors generate little value from the secrecy of their patent applications (**?**Graham and Hegde, 2015), and attach more strategic importance to the duration of pendency *after* the publication of the application (Henkel and Jell, 2010). Unless the inventors mark their products ("pending patent" or "patent applied for"), the existence of a patent application *before* its publication is private information. Disclosing the fact that a technology or invention exists and a patent has been applied for (without disclosing technical details), does not necessarily generate the same effects as the publication of the application including the technical details. This is because, without the details, competitors will not be able to engineer around, nor do inventors forego the opportunity to seek patent protection elsewhere. Announcing the existence of a pending patent, however, can affect rivals and competition in other ways. In this paper, we study when and why patent applicants announce that they have applied for a patent and thus forego the secrecy during the initial 18 months of its pendency—before the automatic publication by the patent office.

We propose a model that captures a simple trade-off. On the one hand, an announcement of a pending patent application informs a firm's rival of potential intellectual property, and this awareness can deter the rival's own innovation. Also, such an announcement can generate uncertainty. Gunderman and Hammond (2007) conclude: "So your competitor's fear of the unknown may provide you a temporary but substantial advantage in the marketplace. Use it well!" A similar argument can be found in Koenen and Peitz (2011). On the other hand, a patent application does

[1]For the United States, Popp et al. (2004) estimate the average pendency of a potential application to be 27 months (for 1976 through 1996), and Hall and Harhoff (2012) find that the average patent in 2002 is pending for 24 months. Both estimates put a considerable amount of time between the publication of pending patent applications and their final examination.

not only hold information about the technology for which patent protection is sought. The fact that a patent has been applied can convey information about the a firm's business and technology management and the composition of its patent portfolio. Disclosing some of this information can have immediate (or short-run consequences).

In our model a technology leader (*she*) and a technology follower (*he*) produce differentiated products and compete in prices. The leader may have access to a cost-reducing technology for which she has a pending patent application. Both the existence and the details of the technology and the patent application are private information. The follower initially produces under the status-quo technology and during stage 1 has the option to innovate. If he decides to innovate, then he gains access to a cost-reducing technology for competition at stage 2. We assume that this decision is publicly observable. Between stage 1 and stage 2, the leader's patent application is published and examined by the patent office. Before the follower makes his innovation decision and the firms compete at stage 1, the applicant leader can announce the existence of a pending patent (without disclosing it technical details), allowing the follower to update his belief about the leader's cost structure at stage 1. Because of the automatic publication of the patent application, competition at stage 2 is always under symmetric information. The follower, however, is aware of the leader's cost-structure at stage 1 only if the applicant leader has disclosed its type.

We assume that both the patent application and, if granted upon examination, the patent are probabilistic. This means the patent is granted with less than certainty. Moreover, provided that it is granted, the patent is then valid with less than certainty. This probability of patent validity can also be interpreted as the probability that the follower's new technology (arriving at stage 2) is infringing on the leader's patent.[2] We refer to the patent's allowance rate (the probability that it granted) as *application strength* and to the probability that the patent is found valid (or that the follower infringes) as *patent strength.* Both application strength and patent strength are common knowledge.

Our model captures a simple inter-temporal trade-off. First, the applicant leader's announcement informs the follower of (probabilistic) property rights that may deter follow-up innovation.

[2]The former interpretation presumes that if the patent is valid, the follow-up technology is infringing with probability one. Under the latter interpretation, the patent is always valid but infringement is probabilistic.

With such an announcement, the follower knows with certainty that a patent application and ensuing patent exists. He further knows that in case of the patent being granted, he will infringe upon this patent with a given probability. If this threat of infringement is sufficiently strong, then it will deter the follower from innovating. This gives the leader a competitive advantage at stage 2, generating licensing revenues that are higher than when the follower innovates. Because the follower's innovation materializes with a delay, this *value of deterring innovation* is a long-run effect.

Second, by announcing the pending patent the leader reveals the existence of the cost-reducing technology and notifies the follower that it produces at lower cost. Given our assumption of price competition (i.e., prices are strategic complements (Bulow et al., 1985)), the follower anticipates lower prices by the leader and will respond with lower prices himself. Announcing the pending patent therefore renders the follower a more aggressive competitor at stage 1. Not announcing the pending patent and keeping the follower in the dark (with softer competition at stage 1) generates a *value of secrecy* in the short run.

The leader's value of deterring innovation ultimately depends on the strength of the leader's intellectual property (i.e., the probability that the follower must pay license fees) and the market life expectancy of the technology (capped by the maximum length of patent protection). In other words, a product or technology generation (to which the cost-reducing technology applies) with a short shelf life yields smaller expected license revenues than one with a longer life cycle. The leader's value of secrecy, on the other hand, is independent of the probability of license fees and the market life expectancy of the technology. The latter is because after the publication of the application there is no more uncertainty in the product market at stage 2.

Juxtaposing the long-run effects of announcing the pending patent (value of deterring innovation) with the short-run costs (value of secrecy), the leader is more likely to announce when the probability of license revenues as well as the duration of license revenues is higher. The same effects, however, make innovation more profitable for the follower. This is because the leader's benefits of deterring innovation are equal to the follower's benefits from innovating.

The equilibrium of the message-innovation game before stage-1 competition yields a non-monotonic relationship between the strength of the leader's intellectual property and her announcement as well as the follower's innovation. The conventional view is that stronger (known) intellectual property rights are more likely to deter innovation. In our model, we assume that the rival is not aware of potential intellectual property unless the applicant leader announces a pending patent. We find that (with patent strength low enough), the applicant is more likely to announce the pending patent (and deter innovation) for intermediate values than low values of application strength. For high values, however, such an announcement is not effective because the follower innovates irrespective of the applicant's choice. Analogously (for application strength high enough), the applicant finds it profitable to deter innovation only for intermediate values of application strength. For low values, deterrence is not effective, whereas for high values deterring innovation has little value because the license revenues in case of innovation are relatively high as the follower is infringing on the patent with sufficiently high probability.

For the model, we make a number of critical assumptions. First, the leader's technology and the patent application are given and not modeled as a decision variable. Second, cost-reducing technologies are substitutes. This implies that if the follower innovates and the resulting technology does not infringe on the leader's patent, then the leader will not generate any license revenues. With complementary technologies this is likely to be different, yielding a possible incentive for the leader to encourage the follower's investment and thus increase expected license revenues.

Third, in line with the rules in the United States and numerous other jurisdictions, all pending patent applications are automatically published (typically) 18 months after the patent has been filed. We assume that the applications are published and examined between the market interaction at stage 1 and stage 2. This implies that there is no pendency of the patent application after its publication. Such pendency (arising from delays at the patent office) is studied in Popp et al. (2004) or Regibeau and Rockett (2010). Harhoff and Wagner (2009) and Henkel and Jell (2010) show that firms attach a strategic value to the pendency period and, if possible, seek to prolong it.

Fourth, the leader's announcement is ex post verifiable. Any deceptive announcement or "false marking" has legal consequences,[3] and we assume these are binding in the sense that a leader without a patent application will not deceptively announce.

We model competition using a reduced-form representation that is able to capture competition in both strategic complements as well as in strategic substitutes. One general prediction of the model is that announcement of pending patent is considerably more frequent when competition is in substitutes, and we present supportive evidence for this prediction.

The structure of the paper is as follows. In Section 2, we introduce the model. In Section **??**, we present the equilibrium results for the price competition at both stages. In Section 3, we derive the equilibrium for the message-innovation game before stage-1 competition and discuss its comparative statics. In Section 4 we present evidence supporting the predictions of the model with respect to the impact of competition, and in Section 5 we conclude. The formal proofs and certain robustness checks are relegated to the Appendix.

2 Model

We consider an industry in which two firms compete in both the technology space and a product market. A technology leader L has access to a new technology (or a new product design), whereas the follower F (initially) produces under a status-quo technology. The technologies are substitutes, and the new (or superior) technology is strictly better than the status-quo technology (we characterize the payoff effects below). The firms are aware of their respective roles; the leader's technology type, however, is known only to the leader.[4] We refer to the leader with a superior technology as a "good" leader (indexed by subscript G) and to the leader without a superior

[3] By Title 35, Article 292, of the U.S. Code ("False marking"), the use of the term "patent pending" or "patent applied for" is permitted so long as a patent application has actually been filed. If these terms are used when no patent application has been filed, it is deemed as a deceptive act and a fine of up to $500 may be imposed for every such offense. Under Forest Group, Inc. v. Bon Tool Co., 590 F.3d 1295 (Fed. Cir. 2009), the current interpretation of "offense" has each mis-marked article constitute an offense, which permits theoretical damages in the hundreds of millions of dollars for high-volume consumer goods.

[4] We study the leader's announcement decision in a model where the follower may also have innovated in the appendix; the results are qualitatively unchanged.

technology (producing under the status-quo technology) as a "bad" leader (indexed by subscript B).[5]

The follower can invest in R&D to develop her own version of the new technology. This version may differ from the leader's version in many dimensions, but it has the same cost-saving effect or consumer-demand effect as the leader's version.[6] The follower's R&D efforts are uncertain, and the outcome is observed (and available in the product market) only with a one-period delay. The extent to which the follower's R&D outcome is uncertain is a partly determined by the leader's R&D outcome. We assume that successful R&D by the leader (exogenous in this model) increases the follower's success probability.[7] Likewise, the follower's beliefs that the leader is a good type increase her own expectations that R&D is going to be successful (Krieger, 2021).

At the outset of the game, the leader can announce the existence of its new technology and thus influence the follower's decision to invest in R&D. We describe the details of the information environment and the leader's announcement below. The two firms compete in the product market space twice. We assume the leader with a superior technology has a patent application, and the announcement of a new technology is equivalent to announcing that the leader has applied for a patent. Following current legal practice in the United States and elsewhere, the leader's patent application is published (after 18 months) regardless of its examination status.[8] We assume that examination and publication of the application take place after stage-1 competition but before the follower observes the outcome of her own R&D efforts and subsequent stage-2 competition. This means that, while stage-1 competition is under asymmetric information (driven by the follower's beliefs about the leader's type), stage-2 competition is under complete information.

[5]We assume one-sided asymmetric information about the leader's type. The respective properties of the technologies (e.g., marginal costs if the technology is a cost-saving technology or consumer's valuation if the technology is a new product design) are known to both firms.

[6]With this modeling assumption, we rule out "leap-frogging" where follow-up innovation is superior to existing (new technology). Note, however, that we do not assume the follower is an imitator, simply using the leader's technology in its own production process. The assumption that the follower's technology differs in many dimensions open up the possibilities for alternative technologies with the same effect.

[7]An alternative assumption could involve potential technology spillovers. Such spillovers would be harder to reconcile with the setting of unobservable R&D outcomes, however.

[8]The American Inventors Protection Act of 1999 requires that utility patent applications be published after eighteen months regardless of grant status unless the applicants assert that they are not pursuing patent protection outside of the United States. See Johnson and Popp (2003), Popp et al. (2004), Aoki and Spiegel (2009), Koenen and Peitz (2011), or Graham and Hegde (2015).

Figure 1: Timeline of the Message-Innovation Game

	$t = 0:$	Leader G with patent application
	$t = 1:$	Leader's announcement
	$t = 2:$	Follower invests in R&D
Stage 1	$t = 3:$	Stage-1 competition
	$t = 4:$	Patent application is published and examined
	$t = 5:$	Leader and follower observe follower's R&D outcome
	$t = 6:$	License negotiations
Stage 2	$t = 7:$	Stage-2 competition

Figure 1 summarizes the timeline of our model. In the following section, we provide more details and structure for the key ingredients of our model. We provide a summary of the notation in Table 1 below.

2.1 Disclosing an Application

For our main results we assume that the good technology leader type G with a new technology has applied for patent, whereas the bad technology leader type B has not. In other words, the existence of a superior technology implies a patent application, and vice versa. We will relax this assumption later in the paper by introducing "bogus" patents (**?**), applied for by leaders without a new technology.

Assumption 1. *The technology leader has a patent application if and only if it is the good type.*

The good technology leader can credibly announce the existence of a patent application (and thus the existence of a new technology by Assumption 1) by sending a message $m = A$ or remain silent, $m = \varnothing$. Such an announcement can be in form of a press release, a public statement, or a *pending patent* mark on a product the firm sells. We assume for the moment that the technology leader can credibly disclose the existence of a technology without revealing any technical details of that technology. This relates to the notion of revealing the *What?* without the *How?* as discussed in Burstein (2012). For instance, 35 U.S. Code §292 prohibits the marking or advertising of products using "any word importing that an application for patent has been made, when no application for patent has been made, or if made, is not pending."[9] As a consequence, only a technology leader with a patent application can announce its existence, implying that the bad leader type is passive (with $m = \varnothing$).[10]

Assumption 2. *The good technology leader (as the only patent applicant) can credibly announce her technology. Her action set is $M_G = \{A, \varnothing\}$. The bad leader (without a patent application) is a passive player with $M_B = \{\varnothing\}$.*

We denote the leader's (mixed) strategy of announcing its technology (or patent application) in $t = 1$ by $\mu_G = \Pr(m = A|G)$ for the good leader an $\mu_B = \Pr(m = A|B) = 0$ for the (passive) bad leader. This means, $\mu \in \{0,1\}$ in pure strategies and $\mu \in [0,1]$ in mixed strategies. We denote the leader's strategy profile by $\bar{\mu} = (\mu_G, \mu_B)$. Upon observing the announcement (or not observing an announcement), the follower can update beliefs $\hat{\theta}_1 \equiv \hat{\theta}(m|\bar{\mu})$ about the leader's type for stage-1 competition. Because only the good leader type can announce an application, $\hat{\theta}(A|\bar{\mu}) = 1$ for all $\bar{\mu} = (\mu_G, 0)$. Without an announcement, the follower updates beliefs following Bayes' rule:

$$\hat{\theta}(\varnothing|\bar{\mu}) = \frac{\Pr(m = \varnothing|G)\Pr(i = G)}{\Pr(m = \varnothing|G)\Pr(i = G) + \Pr(m = \varnothing|B)\Pr(i = B)}$$

where $\Pr(i = G) = \theta$ is the follower's prior belief that the leader is the good type, and $\Pr(i = B) = 1 - \Pr(i = G)$.[11] Moreover, $\Pr(m = \varnothing|G) = 1 - \mu_G$ and $\Pr(m_B = \varnothing|B) = 1$ are the probabilities that the good type and the bad type do not announce the application. Upon observing m, the follower's posterior are:

$$\hat{\theta}_1 \equiv \hat{\theta}(m|\bar{\mu}) = \begin{cases} \hat{\theta}(A|\bar{\mu}) & = & 1 & \text{if } m = A, \text{ for all } \bar{\mu} = (\mu_G, 0) \\ \hat{\theta}(\varnothing|\bar{\mu}) & = & \dfrac{\theta(1-\mu)}{1-\theta\mu} & \text{if } m = \varnothing \end{cases} \tag{1}$$

[9] For the full text, see Appendix D.

[10] Koenen and Peitz (2015) endogenously arrive at this situation by assuming that a firm is motivated by preserving its reputation in a setting of repeated interaction.

[11] The prior belief here is equivalent to the ex-ante, unconditional success probability of R&D. This means that it is also the ex-ante probability that the leader is of the good type.

Stage-1 competition (in $t = 3$) is under asymmetric information with $\hat{\theta}(m|\bar{\mu})$. The respective profits (characterized below) are equilibrium profit from a Bayesian Nash equilibrium in this subgame. Note that, unlike stage-1 competition, stage-2 competition (in $t = 6$) is under complete information. First, the leader's technology is fully revealed by the publication of its patent application in $t = 4$ with follower's beliefs

$$\hat{\theta}_2 = \begin{cases} 1 & \text{if leader is } i = G \\ 0 & \text{if leader is } i = B; \end{cases} \tag{2}$$

and second, we assume that the outcome of the follower's R&D is observed by both firms in $t = 5$.[12] The respective profits (characterized below) are equilibrium profits from a Nash equilibrium under complete information.

2.2 Technology Spillovers and Follower's R&D

Following the leader's announcement (or lack thereof) in $t = 1$, the follower in $t = 2$ invests in R&D at constant cost K. This R&D investment is successful (and the follower has access to her own version of the new technology) with probability $\tilde{\theta} = \tilde{\theta}(\hat{\theta}_1)$. From an ex ante point of view, we assume the leader's and follower's success probabilities are identical (in other words, the follower is not lagging because of lower skill or expertise). Ex ante (i.e., without any updates on the type of the leader), given that the leader is expected to have the new technology with prior probability θ, the follower will expect to obtain her own version of the new technology (conditional on R&D investment) with the same probability θ. Following Krieger (2021), we assume that R&D outcomes are (positively) correlated. This means, the follower can update her beliefs about her own success probability given her beliefs about the leader's success. Let $\tau \in [0, 1]$ capture the

[12] Absent discounting, this assumption is without loss of generality. If the follower's R&D outcome was not immediately observable by the leader, the only uncertainty in stage 2 would be about whether the follower infringes the leader's patent or not. There would be no uncertainty about whether the follower produces the high or the low quality: he will have access to the high quality via the now-public patent document and no incentive not to use this information. The remaining uncertainty about the source of the follower's high quality could be solved, e.g., by the follower's own patent application being published in an additional stage 3, or the leader spending a certain "investigative" effort to determine the source of the follower's knowledge (similar to the market monitoring effort in (Crampes and Langinier, 2002), or via the discovery proceedings following the filing of a patent infringement lawsuit). This way, the leader would receive her licensing fees for stage 2 in the form of infringement damages payments in stage 3.

degree of the technology spillover. For the follower's success probability given uncertainty about the leader's type (i.e., success), we assume the following structural form:

$$\tilde{\theta}(\hat{\theta}_1) = \theta + \tau\left[\hat{\theta}_1 - \theta\right] = (1-\tau)\,\theta + \tau\hat{\theta}_1 \tag{3}$$

The follower's expectations that it will successfully develop her own version of the technology, as function of her own beliefs about the leader's type, is a weighted average of the follower's prior and posterior beliefs about the leader's type (and R&D success). The follower's expectations that her R&D is successful is strictly increasing in her beliefs about the leader's type for all $\tau > 0$.[13]

It is useful to characterize the follower's success probability under complete information. We denote these success probabilities by $\tilde{\theta}_G$ if the leader is of the good type and $\tilde{\theta}_B$ if the leader is of the bad type. Note that these are equivalent to the leader's own expectations about the follower's success (and equivalent to the follower's expectations about its own success probability when knowing the leader's type under complete information with $\hat{\theta}_1 = 1$ if the type is good and $\hat{\theta}_1 = 0$ if the type is bad):

$$\left.\begin{array}{lllllll} \tilde{\theta}_B & = & \theta + \tau\,(0-\theta) & = & (1-\tau)\,\theta & & \\ \tilde{\theta}_G & = & \theta + \tau\,(1-\theta) & = & (1-\tau)\,\theta + \tau & = & \tilde{\theta}_B + \tau \end{array}\right\} \tag{4}$$

The follower's expectations (under incomplete information) are then equal to

$$\tilde{\theta}(\hat{\theta}_1) = \hat{\theta}_1\tilde{\theta}_G + \left(1 - \hat{\theta}_1\right)\tilde{\theta}_B$$

which yields expression (3) above.

2.3 Product Market

We take a reduced-form characterization of product market competition between two firms. This allows us, in a tractable way, to capture both competition in strategic substitutes as well

[13]Note that in a separating equilibrium, in which the good leader announces $m = A$ (and the passive bad leader does not announce), the follower's R&D is no longer uncertain.

as in strategic complements and both cost-reducing as well as demand-increasing innovation. In Appendix C, we show how the key properties of the reduced-form model can be obtained with simple product-market competition models.

For the notation of our reduced-form product-market payoffs, let i and j be two firms that are in direct competition. Firms can be of either a good type (with new technology) or a bad type (without a new technology). Moreover, let π_{ij} denote a firm i's profits (facing firm j) under complete information (when both firms know each other's types). Our reduced form characterization of the product-market profits has the following properties:

Property 1. *With the new technology (good type), firm i obtains a competitive advantage so that $\pi_{GB} > \pi_{GG}$, $\pi_{BB} > \pi_{BG}$, and $\pi_{GG} > \pi_{BB}$.*

For the purpose of our analysis, we normalize firm i's complete information profits when it operates under the status-quo technology and faces a competitor with a good technology to zero, $\pi_{BG} = 0$. The first property then implies the following ordering of complete-information profits:

$$\pi_{GB} > \pi_{GG} > \pi_{BB} > 0 = \pi_{BG}. \tag{5}$$

To simplify analysis we additionally introduce the following property which implies that both firms always find it mutually profitable to license. Appendix F shows that similar results obtain when this property fails to hold.

Property 2. *Firms jointly benefit from knowledge transfer: $2\pi_{GG} > \pi_{GB} + \pi_{BG}$*

Property 3. *In Bayesian Nash equilibrium when firm j does not know firm i's type, firm i's profits are decreasing in firm j's beliefs that i has access to the new technology when the firms compete in strategic complements. Firm i's profits are increasing in firm j's beliefs when the firms compete in strategic substitutes.*

This last property generalizes implications from simple models of price and quantity competition. To see this, consider a simple model of competition à la Bertrand in which prices are strategic complements. Knowledge of firm i's good type (e.g., lower costs) makes firm j a more aggressive competitor, thus reducing firm i's Bayesian equilibrium profits. Conversely, knowledge of firm i's bad type (e.g., higher costs) makes firm j a less aggressive competitor, thus increasing firm i's profits.[14] The reverse patterns apply when firms compete in strategic substitutes, as for instance, in a linear-demand Cournot model.[15]

For our analysis below and following our Property 3, it is useful to characterize the leader's (firm i's) profits as a function of the follower's (firm j's) beliefs $\hat{\theta}_1$. These profits are Bayesian Nash equilibrium payoffs (under incomplete information) in stage 1 and Nash equilibrium payoffs (under complete information) in stage 2.[16] We use $\sigma \in (\underline{\sigma}, \overline{\sigma})$, with $\underline{\sigma} \in (-1, 0)$ and $\overline{\sigma} \in (0, 1)$, to capture the effect of the follower's beliefs on the leader's equilibrium profits. The firms compete in strategic complements if $\sigma > 0$ and strategic substitutes if $\sigma < 0$. In case of $\sigma = 0$, information about the other firm's technology type does not affect a firm's optimal strategy. The (informed) leader's profits $\tilde{\pi}_i$ (with $i = B, G$) in reduced form are then:[17]

$$\tilde{\pi}_i(\hat{\theta}_1) = \begin{cases} \tilde{\pi}_B &= \left(1 - \sigma\hat{\theta}_1\right)\pi_{BB} \\ \tilde{\pi}_G &= \left(1 + \sigma\left(1 - \hat{\theta}_1\right)\right)\pi_{GB} = \left(1 - \sigma\hat{\theta}_1 + \sigma\right)\pi_{GB}. \end{cases} \tag{6}$$

This expression is decreasing in posterior beliefs $\hat{\theta}_1$ for both types. One key implication is that, under strategic complements, the bad type leader prefers complete information (with $\hat{\theta}_1 = 0$) to uncertainty at stage 1 (with $\hat{\theta}_1 > 0$) whereas the good type with the technology prefers uncertainty (with $\hat{\theta} < 1$ to complete information (with $\hat{\theta}_1 = 1$). Under strategic substitutes, these preferences by the leader are reversed.

2.4 Intellectual Property

Patents are generally not ironclad legal rights, but whether a patent is valid (and the ensuing intellectual property right enforceable) is subject to dispute (**???**). We incorporate this feature of

[14] For a textbook treatment, see Saloner (1987), Tirole (1988), Ordover and Saloner (1989), or Vives (1999).

[15] See Appendix C for more details.

[16] Stage-2 payoffs can be also be characterized as equilibrium payoffs from a degenerate Bayesian Nash equilibrium with polar beliefs $\hat{\theta} \in \{0, 1\}$.

[17] These profits under incomplete information reduce to the profits under complete information with $\tilde{\pi}_B(0) = \pi_{BB}$ and $\tilde{\pi}_G(1) = \pi_{GG}$.

intellectual property rights into our model and assume the patent is granted (or, if it is granted, upheld in court) with probability $\gamma \in [0,1]$. We allow for the follower's new version to be sufficiently different so that, even if the leader has a valid patent, the follower's version is not necessarily infringing on the leader's patent. We assume that, conditional on the leader's patent being valid and the follower's R&D success, the follower's technology infringes on the leader's patent with probability $\eta \in [0,1]$. For notational ease, we will write $\beta \equiv (1-\eta)\gamma$.

If the follower does not develop her own version of the technology or infringes on the leader's patent, she can take out a license at a fixed fee λ.[18] A follower who believes the leader is of the good type (with a patent application) and invests in R&D at $t = 2$ expects to pay the license fee with probability

$$\tilde{\theta}_G \gamma \eta + \left(1 - \tilde{\theta}_G\right)\gamma \quad = \quad \gamma - \beta \tilde{\theta}_G;$$

a follower who does not invest expects to pay the license fee with probability γ.

Definition 1. *The perfect Bayesian equilibrium of the message-innovation game is a triple* $\left\{\bar{\mu}, \bar{\rho}, \hat{\theta}_1\right\}$ *with* $\bar{\mu} = (\mu_G, 0)$ *and* $\bar{\rho} = (\rho_A, \rho_\varnothing)$.

3 Equilibrium Analysis of the Baseline Model

In the sequel, we derive the perfect Bayesian equilibria of the message-innovation game described above. We first characterize the outcome of license negotiations in $t = 6$ given the realization of the patent examination process in $t = 4$ and the follower's R&D in $t = 5$. We then derive conditions under which the follower invests in R&D in $t = 2$ and the leader announces its technology in $t = 1$.

[18] We use fixed license fees instead of royalties. In our reduced-form competition model: no room for royalty rates. Also, see **?** for a discussion of efficiency property; also ... check Kamien Tauman

Table 1: Notation for Parameters and Decisions

Variable	**Description**
Decisions / Actions Sets / Strategies	
M_G, M_B	Leader's choice set; $M_G = \{A, \varnothing\}$ and $M_B = \{\varnothing\}$ for passive bad leader.
m, μ_i	Leader's action (announce technology $m = A$ or remain silent $m = \varnothing$) and (mixed) strategy ($\mu_i = \Pr(m = A \mid i)$ with $\mu_B = \Pr(m = A \mid B) = 0$ for the passive bad leader).
$\bar{\mu} = (\mu_G, \mu_B)$	Leader's strategy profile; $\mu_B = 0$.
r, ρ_m	Follower's action ($r = 1$ if invest in R&D, $r = 0$ otherwise) and (mixed) strategy ($\rho_m = \Pr(r = 1 \mid m)$).
$\bar{\rho} = (\rho_A, \rho_\varnothing)$	Follower's strategy profile.
Model Parameters / Functions	
$K \geq 0$	Follower's costs of investing in R&D.
$\theta \in [0,1]$	Prior probability (and follower's prior belief) that leader is of the good type with a new technology, $\theta = \Pr(leader = G)$.
$\hat{\theta}_1 \equiv \hat{\theta}(m \mid \bar{\mu})$	Follower's posterior beliefs about leader's type, upon observing m, given the strategy profile $\bar{\mu} = (\mu_G, \mu_B)$.
$\tau \in [0,1]$	Degree of technology spillover.
$\tilde{\theta}(\hat{\theta}_1) \in [0,1]$	Follower's success probability as function of her beliefs, $\tilde{\theta}(\hat{\theta}_1) = (1-\tau)\,\theta + \tau\hat{\theta}_1$.
$\tilde{\theta}_i$	Follower's success probability, conditional on leader's type, $i = G, B$.
π_{ij}	Complete-information equilibrium profits for a firm $i = G, B$, facing a firm $j = G, B$.
$\sigma \in (\underline{\sigma}, \overline{\sigma})$	Degree of strategic complementarity ($\sigma > 0$) or strategic substitutability ($\sigma < 0$); with $\underline{\sigma} \in (-1, 0)$ and $\overline{\sigma} \in (0, 1)$.
$\tilde{\pi}_i(\hat{\theta}_1)$	Leader i's incomplete-information equilibrium profits when facing a follower with beliefs $\hat{\theta}_1$ about leader's type.
$\gamma \in [0,1]$	Probability that patent is granted (or granted patent is upheld in court if granted).
$\eta \in [0,1]$	Probability (conditional on follower's successful R&D and leader's granted patent) that follower's own version of new technology infringes on leader's patent.
β	$= (1-\eta)\,\gamma$.
λ	License fee the follower pays for using the leader's technology.

3.1 License Negotiations

At the license negotiations stage $t = 6$, the leader's patent application has been examined and the patent granted. Moreover, the follower has not invested in R&D, the investment failed, or the investment was successful but her version of the new technology is infringing on the leader's patent. In these three scenarios, the follower can take out a license and produce under the new technology in stage-2 competition ($t = 7$). Alternatively, the follower produces under the status-quo technology.[19] For the bargaining outcome we assume symmetric Nash bargaining, and the firms split the bargaining surplus equally.

Lemma 1. *The license fee as outcome from a symmetric Nash bargaining solution is* $\lambda = \frac{\pi_{GB}}{2}$.

3.2 Follower's R&D Decision

There are two reasons for the follower to invest in R&D. First, if she believes the leader is of the bad type and operates under the status-quo technology (so that $\hat{\theta}_1 = 0$ and $\tilde{\theta}(\hat{\theta}_1) = \tilde{\theta}_B$), R&D investment can provide for a competitive advantage (with a delay). We denote the profit effect of this competitive advantage in stage-2 competition by $\psi_{F|B}$. It is equal to:

$$\psi_{F|B} \equiv \pi_{GB} - \pi_{BB}; \tag{7}$$

and the expected profit effect of the competitive advantage is $\tilde{\theta}_B \psi_{F|B}$. Second, if the follower believes the leader is of the good type and operates under a new technology (so that $\hat{\theta}_1 = 1$ and $\tilde{\theta}(\hat{\theta}_1) = \tilde{\theta}_G$), then she invests in R&D to avoid having to pay the license fee λ. We denote the license-fee savings as a result of successful R&D investment by $\psi_{F|G}$. Let $\beta = (1 - \eta)\gamma$, then the license-fee savings are:[20]

$$\psi_{F|G} \equiv \beta\lambda = \frac{\beta \pi_{GB}}{2}. \tag{8}$$

For the complete characterization of the follower's payoffs, we use $r = 1$ if the follower has invested and $r = 0$ if otherwise. Given the leader's decision to announce $m \in \{A, \varnothing\}$ and the follower's R&D investment $r \in \{0, 1\}$, the follower's expected net payoffs $\pi_F(m, r)$ in $t = 2$ are

[19] We assume the leader's threat to obtain injunctive relief is credible. See the discussion in Denicolò et al. (2008).

[20] If the follower successfully invests in R&D, she pays the license fee with probability $\gamma\eta$. If she does not invest, she pays the license fee with probability γ. The difference in expected license fees is $-(1-\eta)\gamma\lambda$; the negative thereof is equal to the savings.

equal to:

$$\pi_F(m,r) = \hat{\theta}(m|\bar{\mu})\left[r\left[\pi_{GG}-\gamma\left(\tilde{\theta}_G\eta+\left(1-\tilde{\theta}_G\right)\right)\lambda\right]+(1-r)\left[\pi_{GG}-\gamma\lambda\right]\right]+ \left(1-\hat{\theta}(m|\bar{\mu})\right)\left[r\left[\tilde{\theta}_B\pi_{GB}+\left(1-\tilde{\theta}_B\right)\pi_{BB}\right]+(1-r)\pi_{BB}\right]-rK \tag{9}$$

We can simplify this expression to read:

$$\pi_F(m,r) = \hat{\theta}(m|\bar{\mu})\left[\pi_{GG}-\gamma\lambda+r\tilde{\theta}_G\psi_{F|G}\right]+\left(1-\hat{\theta}(m|\bar{\mu})\right)\left[\pi_{BB}+r\tilde{\theta}_B\psi_{F|B}\right]-rK \tag{10}$$

The follower's expected net benefits from R&D, given the leader's decision m and the follower's beliefs $\hat{\theta}(m|\bar{\mu})$, are defined as the difference between the follower's expected net payoffs when she invests in R&D ($r=1$) relative to when she does not invest in R&D ($r=0$),

$$R(\hat{\theta}(m|\mu)) \equiv \pi_F(m,1)-\pi_F(m,0).$$

Lemma 2. *The follower's expected net benefits from R&D investment, given m and thus $\hat{\theta}_1$, are*

$$R(\hat{\theta}) = \hat{\theta}_1\tilde{\theta}_G\psi_{F|G}+\left(1-\hat{\theta}_1\right)\tilde{\theta}_B\psi_{F|B}-K. \tag{11}$$

The follower invests if $R(\hat{\theta}_1)\geq 0$ and does not invest otherwise.

These expected net benefits are the weighted average of what the follower expects to save in terms of license fees ($\psi_{F|G}$, when the leader is the good type) and what she expects to gain in the product market ($\psi_{F|B}$, when the leader is of the bad type), with the weights the respective posterior beliefs about the leader's type.

A necessary condition for the leader's announcement to have a deterring effect on the follower's decision is $R(\hat{\theta}(\varnothing|\bar{\mu})) > R(\hat{\theta}(A|\bar{\mu})) = R(1)$. It requires that the follower's net benefits after announcing $m=A$ are lower than without announcing. If the necessary condition is not satisfied, then announcing does not deter (as no announcing would make investment by the follower even less likely); in fact, the announcement may trigger the follower's R&D investment. The following

Lemma summarizes the effect of the leader's decision m on the follower's R&D decision. It characterizes three different scenarios: an announcement by the leader can deter or trigger R&D investment by the follower. Moreover, the announcement may be ineffective as the follower will either always invest or never invest regardless of the leader's decision.

Lemma 3.

1. *The leader's announcement $m = A$ deters the follower's R&D investment if $R(\hat{\theta}(\varnothing|\bar{\mu}) \geq 0 > R(\hat{\theta}(A|\bar{\mu})) = R(1)$ or*
$$\frac{K - \left(1 - \hat{\theta}(\varnothing|\bar{\mu})\right)\tilde{\theta}_B \psi_{F|B}}{\hat{\theta}(\varnothing|\bar{\mu})} \leq \tilde{\theta}_G \psi_{F|G} < K.$$

2. *The leader's announcement $m = A$ triggers the follower's R&D investment if $R(\hat{\theta}(\varnothing|\bar{\mu})) < 0 \leq R(1)$ or*
$$\frac{K - \left(1 - \hat{\theta}(\varnothing|\bar{\mu})\right)\tilde{\theta}_B \psi_{F|B}}{\hat{\theta}(\varnothing|\bar{\mu})} > \tilde{\theta}_G \psi_{F|G} \geq K.$$

3. *The leader's announcement $m = A$ is ineffective if either $\min\left\{R(1), R(\hat{\theta}(\varnothing|\bar{\mu}))\right\} \geq 0$ (when the follower always invests, regardless of m) or $\max\left\{R(1), R(\hat{\theta}(\varnothing|\bar{\mu}))\right\} < 0$ (when the follower never invests, regardless of m).*

We can more generally state that the leader's announcement weakens the follower's R&D incentives if $R(\hat{\theta}(\varnothing|\bar{\mu})) > R(1)$ and strengthens it otherwise. For our equilibrium analysis below, the property of the follower's net benefits of R&D as summarized in the following Lemma will prove to be useful.

Lemma 4. *The follower's net benefits from R&D are decreasing in the follower's beliefs $\hat{\theta}$ about the leader's type if and only if*

$$(1 - \tau)\,\theta\left[\psi_{F|G} - \psi_{F|B}\right] + \tau\psi_{F|G} < 0. \tag{12}$$

A necessary condition for condition (12) to hold is

$$\psi_{F|G} = \frac{\beta\pi_{GB}}{2} < \pi_{GB} - \pi_{BB} = \psi_{F|B}.$$

In other words, the competition effect from R&D must be stronger than the license-savings effect. We can expect to see this more often when the leader's application is expected to be weak (γ is low) or broad (η is large) so that the follower's R&D is more likely to infringe. In the former case, the follower expects to pay license fees with lower probability but also anticipates the leader's technology to be free. In the latter case, the follower expects to pay the license fee with higher probability, reducing the license-fee savings.

Given this necessary condition, $\psi_{F|B} > \psi_{F|G}$, condition (12) is satisfied and announcement $m = A$ weakens the follower's R&D incentives if technology spillover effects τ are low, or the prior θ is high.

3.3 Leader's Announcement in Equilibrium

For the full characterization of the equilibria in the message-innovation game, we need to spell out only the good type's strategy. Under Assumptions 1 and 2, the bad type is a passive player with $m = \varnothing$ and $\mu = 0$. We start the analysis with scenario 1, then move to scenario 2. We establish the equilibrium results but delay the discussion of results with graphical illustrations until section 3.4.

3.3.1 Scenario 1: Announcement Weakens the Follower's R&D Incentives

Assume condition (12) is satisfied and the leader's announcement weakens the follower's incentives to invest in R&D. We first consider pure strategies. Then, in a separating equilibrium, the good leader announces, $m = A$, whereas in a pooling equilibrium, the good leader does not announce, $m = \varnothing$. In mixed strategies, the good leader announces with probability μ_G and remains silent with probability $1 - \mu_G$.

The leader, when deciding whether to announce, trades off the payoff consequences in stage-1 competition ($\tilde{\pi}_G(\hat{\theta}(A|\bar{\mu}))$ and $\tilde{\pi}_G(\hat{\theta}(\varnothing|\bar{\mu}))$) against the payoff consequences in stage-2 competition. As discussed in the context of the expressions for $\tilde{\pi}_G$ in equation (6) above, the good leader's stage-1 competition profits are higher after an announcement if the firms compete in strategic substitutes (and $\sigma < 0$); conversely, the profits are lower after an announcement if the firms compete in strategic complements (and $\sigma > 0$).

For Propositions 1 and 2, we first consider the case where the leader's announcement *deters* the follower's R&D investment (when $R(\theta) \geq 0 > R(1)$).

Proposition 1. *Let $R(\theta) \geq 0 > R(1)$. The message-innovation game has the following unique perfect Bayesian equilibrium in pure strategies. The follower invests in R&D if $m = \varnothing$ and does not invest in R&D if $m = A$. Moreover:*

1. *the leader announces and $m = A$ ("separating equilibrium") if*

$$\frac{2\sigma}{(1-\tau)\,\theta + \tau} \leq \beta; \tag{13}$$

2. *the leader does not announce and $m = \varnothing$ ("pooling equilibrium") if*

$$\frac{2\sigma\,(1-\theta)}{(1-\tau)\,\theta + \tau} \geq \beta. \tag{14}$$

Note that for parameter values such that

$$\frac{2\sigma\,(1-\theta)}{(1-\tau)\,\theta + \tau} < \beta < \frac{2\sigma}{(1-\tau)\,\theta + \tau}$$

neither condition (13) nor condition (14) is satisfied. The following Proposition summarizes the ensuing equilibrium in mixed strategies in which the leader announces the technology with probability μ_g^*.

Proposition 2. *Let $R(\theta) \geq 0 > R(1)$. The message-innovation game has the following perfect Bayesian equilibrium in mixed strategies. The follower invests in R&D if $m = \varnothing$ and does not invest if $m = A$. Moreover, the leader announces a pending patent with probability μ_G^*:*

$$\mu_G^* = \frac{1}{\theta} - \frac{1-\theta}{\theta}\frac{2\sigma}{\left[(1-\tau)\,\theta + \tau\right]\beta}. \tag{15}$$

Propositions 1 and 2 assume that the leader's announcement has a deterring effect on the follower's investment. We continue to assume that condition (12) holds true (i.e., announcement weakens the follower's R&D incentives), but either $R(\theta) > R(1) \geq 0$ so that the follower invests or $0 > R(\theta) > R(1)$ so that the follower does not invest—regardless of the leader's message. In either case, the leader announces the technology when the firms compete in strategic substitutes ($\sigma < 0$) and does not announce when the firms compete in strategic complements ($\sigma > 0$). The results in Proposition 3 apply to this scenario of weakened follower's incentives (condition (12) holds) as well as the scenario (discussed in more detail below) of strengthened follower's incentives (condition (12) does not hold).

Proposition 3. *Let* $\min\{R(\theta), R(1)\} \geq 0$*, so that the follower always invests in R&D, or* $0 > \max\{R(\theta), R(1)\}$*, so that the follower never invests in R&D, regardless of the leader's message* m*. In the unique perfect Bayesian equilibrium of the message-innovation game, the leader announces and* $m = A$ *("separating equilibrium") if* $\sigma \leq 0$*; the leader does not announce and* $m = \varnothing$ *("pooling equilibrium") if* $\sigma \geq 0$*.*

3.3.2 Scenario 2: Announcement Strengthens the Follower's R&D Incentives

For a full picture of the model, we now consider the case where the leader's announcement strengthens the follower's investment incentives (when condition (12) is not satisfied). Recall that the results in Proposition 3 apply to the case under this scenario where the follower either always invests in R&D or never invests in R&D. The results discussed below thus apply only to the case in which the leader's announcement *triggers* R&D investment by the follower, that means, when $R(1) \geq 0 > R(\theta)$ and $R(\theta')$ increasing in θ'. Such a scenario arises when there are strong technology spillover effects (**??**) and firms' learn from their competitors' R&D success. Propositions 4 summarizes the results.

Proposition 4. *Let* $R(1) \geq 0 > R(\theta)$*. The message-innovation game has the following perfect Bayesian equilibrium in pure strategies. The follower invests in R&D if* $m = A$ *and does not invest in R&D if* $m = \varnothing$*. Moreover:*

1. the leader announces and $m = A$ ("separating equilibrium") if

$$-\frac{2\sigma}{(1-\tau)\,\theta+\tau} \geq \beta; \tag{16}$$

2. the leader does not announce and $m = \varnothing$ ("pooling equilibrium") if

$$-\frac{2\sigma\,(1-\theta)}{(1-\tau)\,\theta+\tau} \leq \beta. \tag{17}$$

The equilibrium is not unique for parameter values such that both of these conditions are satisfied. A necessary condition for multiple equilibria is $\sigma < 0$. When both equilibria exist, the leader prefers the pooling equilibrium.

3.4 Summary and Discussion

A good leader announces if the *value of secrecy* is more than offset by the *value of deterring R&D*. The value of secrecy is determined by the effect of information on stage-1 competition profits. When firms compete in strategic complements, so that $\sigma > 0$ and $\tilde{\pi}_G$ decreasing in θ, the value of secrecy for the good leader is positive, $\tilde{\pi}_G(\theta) > \tilde{\pi}_G(1)$; when firms compete in strategic substitutes, the value of secrecy is negative. For bad leaders, these patterns are reversed. The value of deterring R&D is determined by the characteristics of intellectual property (β) and the degree of technology spillovers (τ). Condition (12) summarizes that effect: if it holds, the leader's announcement weakens the follower's investment incentives. Moreover, if $R(\hat{\theta}(\varnothing|\mu)) \geq 0 > R(1)$ the announcement deters the follower's investment, and the value of deterring R&D is positive.

Consider a technology space and a product market without spillovers and information effects, $\tau = 0 = \sigma$. The value of secrecy in this case is zero, the value of deterring information depends, among other things, on the characteristics of intellectual property. Suppose the leader's action does not affect the follower's choice, then the leader is indifferent between announcing and remaining silent. If σ is strictly positive, so that the value of secrecy is strictly positive, then the leader will not announce; if σ is strictly negative, the value of secrecy is negative and the leader announces

(Proposition 4). In this latter case, the technology leader gains a competitive advantage from communicating to her competitors (through, e.g., a patent pending mark) that she has successfully developed a new technology.

Now suppose, instead, condition (12) holds and the leader's announcement deters the follower's R&D. By condition (13), the leader always announces when $\sigma < 0$ (with a negative value of secrecy). In this case, announcing has a positive effect on both stage-1 and stage-2 payoffs. If, instead, $\sigma > 0$, the value of secrecy is positive, and the leader must balance the tradeoff between stage-1 payoffs and stage-2 payoffs. By Proposition 1, the leader does not announce if σ is sufficiently high (and the value of secrecy sufficiently strong).

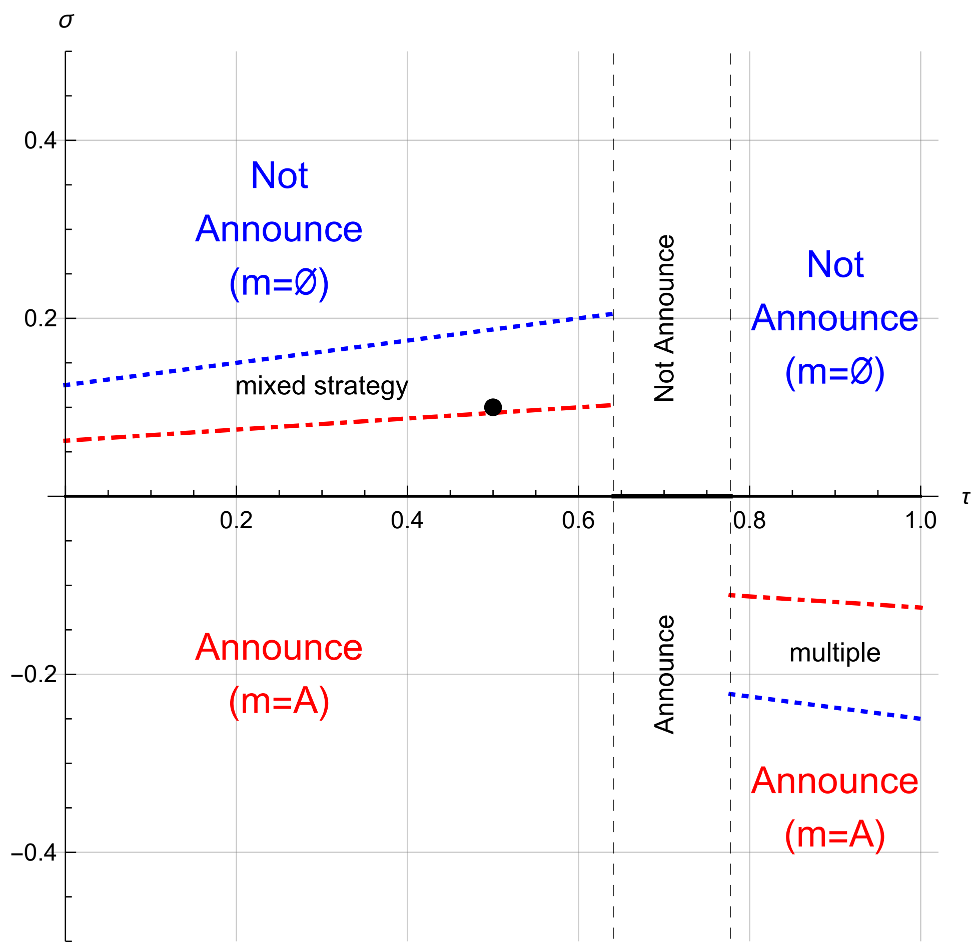
Last, suppose condition (12) is violated and the technology spillover effect is sufficiently strong so that the leader's announcement triggers the follower's R&D investments. The follower learns enough about her own chances of successfully developing her own version of the new technology. This positive effect more than offsets the negative payoff effect from learning about the leader's intellectual property. Recall that the leader's announcement is a signal for both successful R&D (which strengthens the follower's R&D incentives) and potential intellectual property (which weakens the follower's R&D incentives). In this case, the leader's balance is tipped against announcement. The leader does not announce even if the value of secrecy is negative (for some negative values of σ) (Proposition 4).

In Figure 2, we plot the equilibria with technology spillovers τ on the horizontal axis and information effects σ on the vertical axis. See the figure notes for the parameterization of the model.

In Figure 3, we plot the equilibria with β on the horizontal axis and prior beliefs on the vertical axis. See the figure notes for the parameterization of the model.

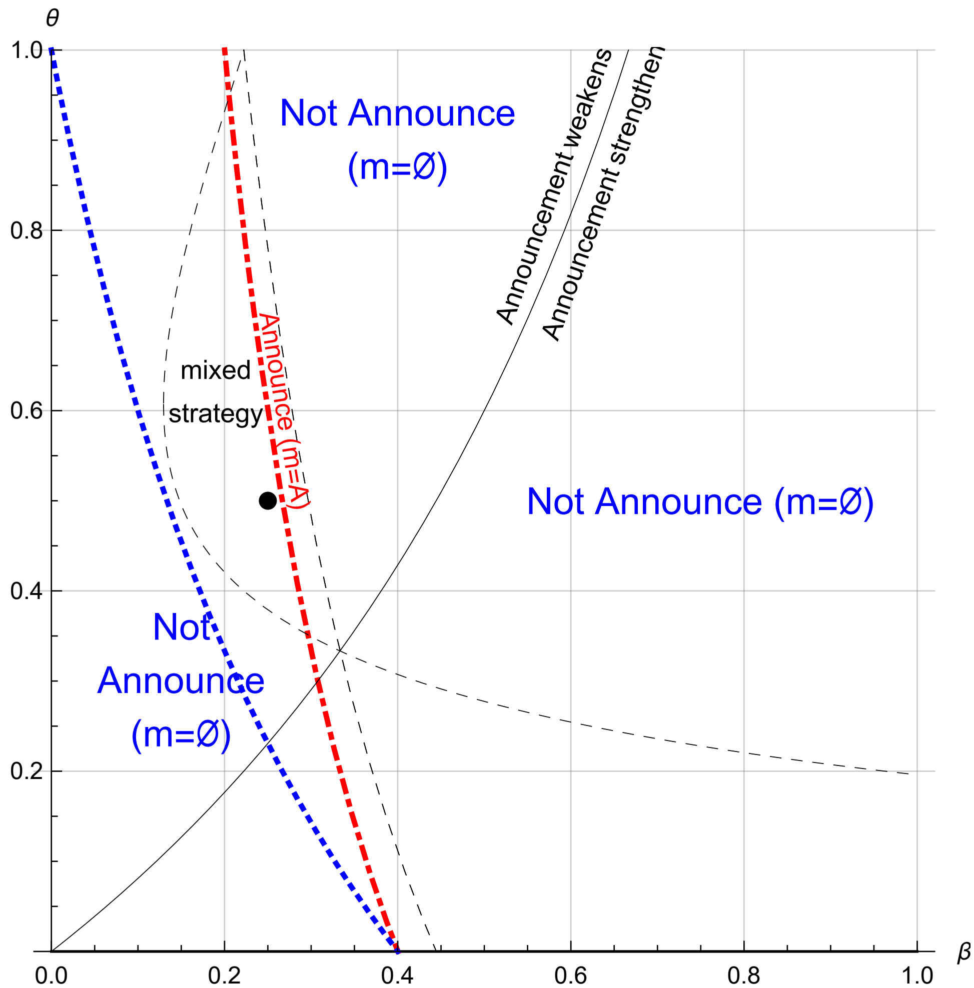
To summarize, our results suggest firms (as technology leaders) do not announce their technologies (and patent applications) in product markets in which giving up information about business or technology strategy comes with large negative profit effects (high value of secrecy for high value of σ) and in technology spaces in which learning about competitor's success reveals a lot about one's own R&D prospects. For instance, consider the scenario in which spillover effects are

Figure 2: Equilibria in (τ, σ) Space – Spillover Effects



Notes: Equilibria in (τ, σ) space (capturing technology and product-market spillovers) for $\theta = 1/2$, $\eta = 1/2$, $\gamma = 1/2$, $\pi_{GB} = 3$, $\pi_{GG} = 2$, $\pi_{BB} = 1$, and $K = 1/3$.

Figure 3: Equilibria in (β, θ) Space – Intellectual Property



Notes: Equilibria in (β, θ) space (capturing strength and existence of intellectual property), where $\beta = (1 - \eta)\gamma$, for $\tau = 1/2$, $\sigma = 1/10$, $\pi_{GB} = 3$, $\pi_{GG} = 2$, $\pi_{BB} = 1$, and $K = 1/3$.

not too strong and an announcement deters innovation. Then firms are best off announcing when

$$\beta \le \frac{2\sigma}{\theta + (1-\theta)\,\tau} \tag{18}$$

This is condition (13) in Proposition 1. If $\sigma < 0$; never announce. Necessary condition is $\sigma > 0$.

4 Empirics

4.1 Hypotheses

The inequalities defining propositions 1 and 4 depend on the values of σ, τ, θ and β, and implicitly on the value of K. We currently restrict our empirical analysis to the effect of σ and τ:

Hypothesis 1. *Announcement of pending patent applications is more frequent when market competition is in substitutes rather than in complements. (qualitative prediction)*

This hypothesis restricts attention to a dichotomous distinction between industries that compete in substitutes and those that compete in complements. We have previously established, however, that the threshold from which onwards L finds it optimal to announce her pending patent does not have to coincide with the distinction between competition modes. Hence, we can add a second, related, hypothesis:

Hypothesis 2. *Announcement of pending patent applications is more frequent when σ decreases. (quantitative prediction)*

Independent of which competition mode prevails, a greater amount of information transmission to the follower about his R&D prospects makes announcement less attractive to the leader:

Hypothesis 3. *Announcement of pending patent applications is more frequent when τ decreases.*

Finally, we can make a prediction concerning the interaction of both variables. When τ is relatively small, L will always announce when competition is in substitutes, but changes in σ may affect the announcement decision when competition is in complements. The opposite is true when

τ is relatively large. Hence, we expect the impact of changes in the absolute value of σ to depend on the value of τ:

Hypothesis 4. *For small (large) τ, announcement of pending patent applications is more frequent when $|\sigma|$ decreases (increases).*

In regression, we therefore expect the coefficient of the main effect of $|\sigma|$ to be negative but the interaction between σ and τ to be positive. We are currently obtaining data that will allow us to measure the other core variables of the model, which will help shedding light on further predictions (see subsection 4.3.1 below).

4.2 Data

4.2.1 Announcing pending patent applications

We use two sources to measure announcement of pending patent applications, (A) press releases and (B) requests for early publication of patent applications to the USPTO.

Press releases. We search for press releases on NexisUni[21] using variations of the search terms "('patent application' OR 'patent applications') AND ('files' or 'filed')". We then restrict results to source types "press releases", "newswires" and similar, published between the years 2015 and 2021, in the region "United States". This search yielded around 30,000 results, of which we download the fulltext. We classified each downloaded search result as to whether it really announces a pending patent application (and not, e.g., a patent grant), and whether it was released by the patent application (instead of, e.g., an industry news source). We end up with 1,797 "true pending patent announcements" via press releases in the US. We identify each issuing company on ORBIS to obtain standardised industry codes.

We are currently working on testing the model's prediction with an alternative data source of patent application announcements; mentions of patent applications in firms' SEC filings. While there is likely a greater level of noise in this measure compared to press releases that contain no

[21] See https://www.lexisnexis.com/en-us/professional/academic/nexis-uni.page.

further information than the existence of the filed patent application, it increases the link between the (non-)announcing firm and the calculated measure of competition.

4.2.2 Measuring the nature of competition σ

We rely on an approach introduced to the corporate finance literature by Kedia (2006). Following Bulow et al. (1985), the nature of competition in an industry is determined by the sign of the cross-partial derivative of a firm's profit with respect to it's competitor(s) strategic variable.

Kedia (2006) suggests to approximate the value of this cross-derivative as follows. The total differential of marginal profit can be expressed as

$$d\left[\frac{\partial \pi^i}{\partial s^i}\right] = \beta_1 s^i \,\mathrm{d}s^i + \beta_2 \,\mathrm{d}s^i + \beta_3 s^i \,\mathrm{d}s^{-i} + \beta_4 \,\mathrm{d}s^{-i} \tag{19}$$

(this corresponds to equation (2) in Kedia 2006). Marginal profit can be approximated as as the quarterly change in a firm's net income ($\Delta\pi^i$) divided by the quarterly change in the firm's net sales (Δs^i). $\mathrm{d}s^{-i}$ is the change in the total output of all competitors, i.e., all other firms in the same industry. Equation (19) is then estimated by OLS, and the cross-partial derivative is approximated by the linear combination

$$\hat{\beta}_3 \bar{s}_i + \hat{\beta}_4, \tag{20}$$

where $\bar{s}_i$ is the mean value of s_i during the sample period used in estimation.

Since data on earnings are publicly virtually unavailable for privately held firms, we only consider publicly traded firms for this part of the analysis. To the extent that all firms in an industry use the same strategic variable, using a subset of very large and stable firms should yield reliable results and is standard practice in the finance literature (Sundaram et al. 1996; Kedia 2006; Chod and Lyandres 2011; Frésard and Valta 2016). Data in Compustat is also available at the quarterly level, which may allow more precise measurement of firms' reaction to each other than the yearly data that is available for privately-held firms in ORBIS.

We use five years of data to calculate the measure of competition for a single year (following Chod and Lyandres 2011); i.e., the competition measure for the year 2020 is calculated using quarterly data from 2016-2020. We then compute the average of the yearly competition measures for the eleven-year time period 2010 to 2020.[22]

4.3 Measuring the extent of correlation of competitors' R&D

We proxy the value of τ as the industry average of the pairwise similarity between firms' "product market" descriptions in their annual 10-K filings to the SEC, which we obtain from data prepared by Hoberg and Phillips (2016). While at first glance this measure seems to capture aspects of the extent of product differentiation and therefore of $|\sigma|$, the relevant sections in the SEC filings are written at a "high" and abstract level that does not allow immediate comparison between individual product markets.

Nonetheless, we are currently working to see if we can replicate these results using Jaffe's 1986 patent-data based measure of technological similarity of firms' patent portfolios, a variable that is more widely adopted by existing literature but that takes considerably longer time to calculate for the large number of industry samples that we need to cover.

4.3.1 Empirically measuring further variables of the theoretical model

To allow testing further predictions of the model, we are currently working on measuring the following variables:

- γ Probability of patent granting via relative frequency of claim allowance per industry; this information can be constructed from the USPTO's Patent Examination research dataset.

- η Probability of patent infringement via either industry average similarity of patents to their prior art (text similarity between patents and their backward citations, Kuhn et al. 2020) or via the relative frequency of infringement litigation in an industry (data provided by the USPTO's Patent Litigation Docket Reports dataset).

[22] Using the six-year time period 2015-2020 yields similar results.

4.4 Results

We obtain a measure of competition for 310 6-digit NAICS industries that contain at least two publicly traded firms.[23] Of these, 151 6-digit NAICS industries are considered to feature competition in complements and 159 industries competition in substitutes. Industries with competition in substitutes feature on average 1.78 announcing firms, compared to 1.1 announcing firms per industry with competition in complements, in line with hypothesis 1 (see Table 2).

The Kedia measure can only identify the sign, but not the magnitude, of σ. We therefore create a new variable at the firm level that takes value 1 if the Kedia estimate is positive and value -1 if the Kedia estimate is negative. We then approximate the absolute value of σ in an industry by taking the average over all firms in that industry.

As our primary analysis (and the only one reported in this conference submission) we run a logistic regression at the industry level, using as dependent variable a binary indicator that takes value 1 if at least one press release announcing a pending patent application has been assigned to this industry, and value 0 otherwise. In line with hypothesis 2, we find a significant negative association between the occurrence of patent announcements and our measure of σ (see Table 3). The estimated relationship becomes stronger and more precise when we additionally control for the share of very small firms (with fewer than 5 employees) among all firms in the industry, obtained from 2019 establishment data from the US Census Bureau.[24] This control variable captures the relative importance of patent applications as means of startup firms to attract outside financing such as venture capital, and the results indicate that our mechanism is an additional reason for disclosing patent applications that coexists with the more established reason.

The industry average of our proxy for τ based on Hoberg and Phillips (2016) is also negatively associated with the occurrence of announcement, supporting hypothesis 3. Finally, in column 4 we regress the absolute value of the proxy for σ instead of its original value and additionally interact it with our proxy for τ. As predicted by 4, we find that the estimate for the main effect of $|\sigma|$ is negative while the estimate for the interaction is positive.

[23] Industries for which Compustat provides data for a single firm only are discarded since we are unable to calculate a measure of firm interaction. For 22 industries the estimated measure is not significantly different from zero, and we also discard those industries from our analysis.

[24] Similar results obtain when using an employment thresholds of 10 and 20.

Competition in	complements	substitutes	not classified
Number of industries	151	159	22
Number of industries w/ announcement(s)	45	56	8
Mean no. announc. firms	1.1	1.78	0.77
Mean "intensity of interaction" ($\lvert\sigma\rvert$):			
in industries w/ announcement:	.28	-.31	
in industries w/o announcement:	.39	-.31	

Table 2: Summary statistics of the regression dataset

	(1)	(2)	(3)	(4)
$\hat{\sigma}$ (Kedia, 2006)	-.503*	-.781**	-.775**	
	(.289)	(.311)	(.327)	
Share of firms <5 emp.		1.843***	2.003***	1.754**
		(.660)	(.691)	(.700)
τ (Hoberg & Philips, 2016)			-6.317***	-8.345***
			(2.401)	(2.648)
$\lvert\hat{\sigma}\rvert$				-5.030*
				(2.725)
$\lvert\hat{\sigma}\rvert \times \tau$				61.411*
				(32.534)
constant	-.72***	-1.362***	-.755*	-.470
	(.117)	(.320)	(.399)	(.417)
N	332	298	285	285
Log. lik.	-208.6	-188.2	-177.3	-175.7

Table 3: Results from simple logistic regressions of an announcement dummy variable

5 Discussion and Concluding Remarks

In many jurisdictions, the existence and contents of patent applications are unknown to third parties until the application is published by the patent office at least 18 months after the initial filing. The patent applicant can expedite this public awareness of the existing application and the respective technology by announcing the patent application before its automatic publication. We study this decision in a model that captures the inter-temporal trade-off an applicant faces. On the one hand, an announcement of a pending patent application informs a firm's rival of potential intellectual property, and this awareness can deter the rival's own innovation. On the other hand, a patent application does not only hold information about the technology for which patent protection is sought. The fact that a patent has been applied can convey information about the a firm's business and technology management and the composition of its patent portfolio. Disclosing some of this information can have immediate (or short-run consequences).

In our model, the applicant balances this negative effect of disclosure on its informational advantage in the short run (*value of secrecy*) with a positive long-run effect stemming from potential deterrence of a rival's R&D (*value of deterring innovation*). We give conditions under which announcing the pending patent deters a rival's innovation. We show that, in equilibrium, the applicant's decision to announce and the rival's decision to innovate are non-monotonic in the strength of the application and the strength of the patent. This implies that stronger intellectual property rights do not always deter innovation when an applicant does not find it profitable to inform a rival of its pending status. We also show that—all else equal—the applicant will be announcing more often when competition is in substitutes.

We produce evidence supporting core predictions using press releases on patent application filings by US firms. In doing so, we provide evidence supporting the theoretical prediction going back to Gal-or (1986) and expanded on by Darrough (1993) and Hughes and Pae (2015) that production cost disclosure depends on the mode of competition in an industry.[25] Using patent applications as one relatively easily observable signal of the production cost level, we adapt the

[25] Sundaram et al. (1996) are the first to attempt to empirically identify the mode of competition for a large number of industries, but their attention is on the effect of (R&D) announcements on firms' stock prices, not on the (non-)occurrence of such announcements.

model and qualify the predictions for this special context. We are currently working on providing evidence for several further predictions of the model.

References

Aoki, R. and Y. Spiegel (2009): "Pre-Grant Patent Publication and Cumulative Innovation," *International Journal of Industrial Organization*, 27, 333–345. [Cited on page 7.]

Bessen, J. E. and M. J. Meurer (2006): "Patent Litigation with Endogenous Disputes," *American Economic Review*, 96, 77–81. [Cited on page 2.]

Bulow, J. I., J. D. Geanakoplos, and P. D. Klemperer (1985): "Multimarket Oligopoly: Strategic Substitutes and Complements," *Journal of Political Economy*, 93, 488–511. [Cited on pages 4 and 28.]

Burstein, M. J. (2012): "Exchanging Information Without Intellectual Property," *Texas Law Review*, 91, 227–282. [Cited on page 8.]

Chod, J. and E. Lyandres (2011): "Strategic IPOs and product market competition," *Journal of Financial Economics*, 100, 45–67. [Cited on pages 28 and 29.]

Crampes, C. and C. Langinier (2002): "Litigation and Settlement in Patent Infringement Cases," *The RAND Journal of Economics*, 33, 258–274. [Cited on page 10.]

Darrough, M. N. (1993): "Disclosure Policy and Competition: Cournot vs. Bertrand," *The Accounting Review*, 68, 534–561. [Cited on page 32.]

Denicolò, V., D. Geradin, A. Layne-Farrar, and J. A. Padilla (2008): "Revisiting Injunctive Relief: Interpreting ebay in High-Tech Industries with Non-Practicing Patent Holders," *Journal of Competition Law & Economics*, 4, 571–608. [Cited on page 16.]

Frésard, L. and P. Valta (2016): "How Does Corporate Investment Respond to Increased Entry Threat?" *The Review of Corporate Finance Studies*, 5, 1–35. [Cited on page 28.]

Gal-or, E. (1986): "Information Transmission—Cournot and Bertrand Equilibria," *The Review of Economic Studies*, 53, 85–92. [Cited on pages 1 and 32.]

Graham, S. and D. Hegde (2015): "Disclosing patents' secrets," *Science*, 347. [Cited on pages 2 and 7.]

Gunderman, R. and J. Hammond (2007): "Patent Pending: A Warning to Would-be Competitors," *The Rochester Engineer*, 7. [Cited on page 2.]

Hall, B. and D. Harhoff (2012): "Recent Research on the Economics of Patents," *Annual Review of Economics*, 4, 541–565. [Cited on page 2.]

Harhoff, D. and S. Wagner (2009): "The Duration of Patent Examination at the European Patent Office," *Management Science*, 55, 1969–1984. [Cited on page 5.]

Henkel, J. and F. Jell (2010): "Patent Pending: Why Faster Isn't Always Better," Unpublished manuscript. [Cited on pages 2 and 5.]

Hoberg, G. and G. Phillips (2016): "Text-Based Network Industries and Endogenous Product Differentiation," *Journal of Political Economy*, 124, 1423–1465. [Cited on pages 29 and 30.]

Hughes, J. S. and S. Pae (2015): "Discretionary Disclosure, Spillovers, and Competition," *Review of Accounting Studies*, 20, 319–342. [Cited on page 32.]

Jaffe, A. B. (1986): "Technological Opportunity and Spillovers of R & D: Evidence from Firms' Patents, Profits, and Market Value," *The American Economic Review*, 76, 984–1001. [Cited on page 29.]

Johnson, D. K. and D. Popp (2003): "Forced Out of the Closet: The Impact of the American Inventors Protection Act on the Timing of Patent Disclosure," *RAND Journal of Economics*, 34, 96–112. [Cited on page 7.]

Kedia, S. (2006): "Estimating product market competition: Methodology and application," *Journal of Banking & Finance*, 30, 875–894. [Cited on page 28.]

Koenen, J. and M. Peitz (2011): "The Economics of Pending Patents," Working Paper 3657, CESifo Group Munich. [Cited on pages 2 and 7.]

——— (2015): "Firm reputation and incentives to âmilkâ pending patents," *International Journal of Industrial Organization*, 43, 18–29. [Cited on page 9.]

Krieger, J. L. (2021): "Trials and Terminations: Learning from Competitors' R&D Failures," *Management Science*, 67, 5525–5548. [Cited on pages 7 and 10.]

Kuhn, J. M., K. Younge, and A. C. Marco (2020): "Patent citations reexamined," *The RAND Journal of Economics*, 51, 109–132. [Cited on page 29.]

Modigliani, F. (????): An Open Letter To the U.S. Senate. [Cited on page 2.]

Motta, M. (1993): "Endogenous Quality Choice: Price vs. Quantity Competition," *The Journal of Industrial Economics*, 41, 113–131. [Cited on page 40.]

Muthoo, A. (1999): *Bargaining Theory with Applications*, Cambridge, UK: Cambridge University Press. [Cited on page 36.]

Ordover, J. A. and G. Saloner (1989): "Predation, Monopolization and Antitrust," in *Handbook of Industrial Organization*, ed. by R. Schmalensee and R. D. Willig, Amsterdam: North-Holland, vol. 1, chap. 9, 537–596. [Cited on page 13.]

Popp, D., T. Juhl, and D. K. Johnson (2004): "Time In Purgatory: Examining the Grant Lag for U.S. Patent Applications," *Topics in Economic Analysis & Policy*, 4, Article 29. [Cited on pages 2, 5, and 7.]

Regibeau, P. and K. Rockett (2010): "Innovaton Cycles and Learning at the Patent Office: Does the Early Patent Get the Delay?" *Journal of Industrial Economics*, 58, 222–246. [Cited on page 5.]

Saloner, G. (1987): "Predation, Merger, and Incomplete Information," *RAND Journal of Economics*, 18, 165–186. [Cited on page 13.]

Singh, N. and X. Vives (1984): "Price and Quantity Competition in a Differentiated Duopoly," *The RAND Journal of Economics*, 15, 546–554. [Cited on page 39.]

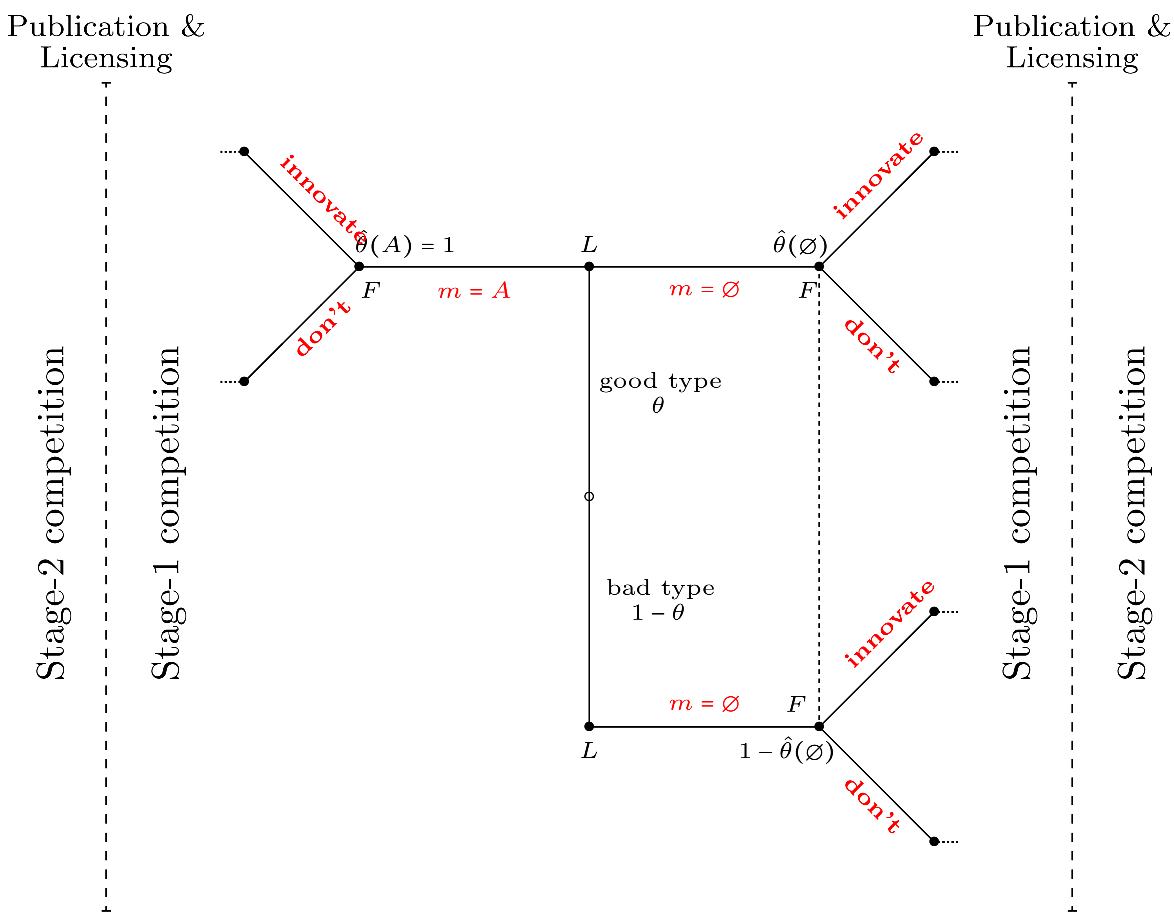
Sundaram, A. K., T. A. John, and K. John (1996): "An empirical analysis of strategic competition and firm values the case of R&D competition," *Journal of Financial Economics*, 40, 459–186. [Cited on pages 28 and 32.]

Tirole, J. (1988): *The Theory of Industrial Organization*, Cambridge, MA: MIT Press. [Cited on page 13.]

Vives, X. (1999): *Oligopoly Pricing: Old Ideas and New Tools*, Cambridge, MA: MIT Press. [Cited on page 13.]

A Additional Figures

Figure A.1: Game Tree for Baseline Model (Assumption 1)



B Formal Proofs

Proof of Lemma 1

Proof. The symmetric Nash bargaining solution implies an equal split of the bargaining surplus (Muthoo, 1999:page 15). This surplus is $2\pi_{GG} - (\pi_{GB} + \pi_{BG}) = 2\pi_{GG} - \pi_{GB}$ and positive by Property 2. The leader's total payoffs are then equal to $\pi_{GB} + \frac{2\pi_{GG}-\pi_{GB}}{2} = \pi_{GG} + \frac{\pi_{GB}}{2}$, implying a license fee of $\lambda = \frac{\pi_{GB}}{2}$. Q.E.D.

Proof of Lemma 3

Proof. 1. Without an announcement (so that $R(\hat{\theta}(\varnothing|\bar{\mu})) \geq 0$) the follower invests; the announcement (so that $R(1) < 0$) renders the follower's net benefits from R&D negative, and the follower does not longer invest.

2. Without an announcement (so that $R(\hat{\theta}(\varnothing|\bar{\mu})) < 0$) the follower does not invest; the announcement (so that $R(1) \geq 0$) renders the follower's net benefits from R&D positive, and the follower invests.

3. If $\min\left\{R(1), R(\hat{\theta}(\varnothing|\bar{\mu}))\right\} \geq 0$, then then follower's net benefits are nonnegative regardless of m; if $\max\left\{R(1), R(\hat{\theta}(\varnothing|\mu))\right\} < 0$, then the follower's net benefits are negative regardless of m.

Q.E.D.

Proof of Lemma 4

Proof. Net benefits $R(\hat{\theta}_1)$ are increasing in $\hat{\theta}_1$ if

$$\frac{dR(\hat{\theta}_1)}{d\hat{\theta}_1} = \tilde{\theta}_G \psi_{F|G} - \tilde{\theta}_B \psi_{F|B} < 0.$$

Recall that $\tilde{\theta}_G = \tilde{\theta}_B + \tau = (1-\tau)\,\theta + \tau$. The above condition can be rewritten to read conditon (12). Q.E.D.

Proof of Proposition 1

Proof. The follower's equilibrium strategies follow from the assumption that $R(\theta) \geq 0 > R(1)$. For the leader's strategy, first consider a separating equilibrium, $\mu_G = 1$. The leader's payoffs when it announces (and the follower does not innovate) are

$$\tilde{\Pi}_G(\hat{\theta}(A|\,(1,0))) = \pi_{GB} + \pi_{GG} + \gamma\lambda.$$

If (off equilibrium) the leader does not announce (and the follower innovates because her beliefs are $\hat{\theta}(\varnothing|\,(1,0)) = 0$), then her payoffs are:

$$\tilde{\Pi}_G(\hat{\theta}(\varnothing|\,(1,0))) = (1+\sigma)\,\pi_{GB} + \pi_{GG} + \gamma\lambda - \tilde{\theta}_G \psi_{F|G}$$

with $\gamma\lambda - \tilde{\theta}_G \psi_{F|G} \geq 0$. A separating equilibrium thus exists if $\tilde{\Pi}_G(\hat{\theta}(A|\,(1,0))) \geq \tilde{\Pi}_G(\hat{\theta}(\varnothing|\,(1,0)))$. Rearranging this condition and using the expressions for $\tilde{\theta}_G$ and $\psi_{F|G}$ yields condition (13) in the Proposition.

Now, consider a pooling equilibrium, where the leader does not announce in equilibrium, $\mu = 0$. On the equilibrium path (observing $m = \varnothing$ and $\hat{\theta}(\varnothing|\,(0,0)) = \theta$), the follower invests in R&D. The leader's equilibrium payoffs are:

$$\tilde{\Pi}_G(\hat{\theta}(\varnothing|\,(0,0))) = \big(1+\sigma\,(1-\theta)\big)\,\pi_{GB} + \pi_{GG} + \gamma\lambda - \tilde{\theta}_G \psi_{F|G}$$

If (off equilibrium), the leader announces, $m = A$, then $\hat{\theta}(A|0) = 1$ and the follower does not invest in R&D. The leader's off-equilibrium payoffs are:

$$\tilde{\Pi}_G(\hat{\theta}(A|\,(0,0))) = \pi_{GB} + \pi_{GG} + \gamma\lambda$$

A pooling equilibrium exists $\tilde{\Pi}_G(\hat{\theta}(\varnothing|\,(0,0))) \geq \tilde{\Pi}_G(\hat{\theta}(A|\,(0,0)))$. Rearranging this condition and using the expressions for $\tilde{\theta}_G$ and $\psi_{F|G}$ yields condition (14) in the Proposition. Because $1-\theta \leq 1$, there is no β such that both conditions (13) and (14) are satisfied. Q.E.D.

Proof of Proposition 2

Proof. First, note that $R(\hat{\theta}(\varnothing|\bar{\mu})) \geq R(\theta)$ for all $\bar{\mu} = (\mu_G, 0)$, so that the deterrence condition holds for all $\bar{\mu}$. In other words, if the leader announces, the follower invests if and only if the (good) leader does not announce (for any given strategy μ_G). The (good) leader is willing to announce with probability μ_G if her payoffs from $m = A$,

$$\tilde{\Pi}_G(\hat{\theta}(A|\bar{\mu})) = \tilde{\pi}_G(\hat{\theta}(A|\bar{\mu})) + \pi_{GG} + \gamma\lambda = \pi_{GB} + \pi_{GG} + \gamma\lambda = \tilde{\Pi}_G(1) \tag{B.1}$$

are equal to her payoffs from $m = \varnothing$ (given $\bar{\mu}$),

$$\tilde{\Pi}_G(\hat{\theta}(\varnothing|\bar{\mu})) = \tilde{\pi}_G(\hat{\theta}(\varnothing|\bar{\mu})) + \pi_{GG} + \gamma\lambda - \tilde{\theta}_G\psi_{F|G}. \tag{B.2}$$

The equilibrium mixed strategy profile $\bar{\mu}^* = \left(\mu_G^*, 0\right)$ is then such that $\tilde{\Pi}_G(1) = \tilde{\Pi}_G(\hat{\theta}(\varnothing|\bar{\mu}^*))$. After some rearranging, we obtain the expression in (15) in the Proposition. Q.E.D.

Proof of Proposition 3

Proof. For either $\min\left\{R(\theta), R(1)\right\} \geq 0$ or $0 > \max\left\{R(\theta), R(1)\right\}$, the leader's stage-2 payoffs are not affected by her decision (the follower's investment decision is independent of m). In a separating equilibrium, the leader announces (so that $\hat{\theta}(A|\bar{\mu}) = 1$) if the stage-1 profits are higher than from not announcing off equilibrium ($\hat{\theta}(\varnothing|\bar{\mu}) = 0$), that means, if $\tilde{\pi}_G(1) \geq \tilde{\pi}_G(0)$ or

$$\pi_{GB} \geq (1+\sigma)\,\pi_{GB} \tag{B.3}$$

which holds true for all $\sigma \leq 0$. In a pooling equilibrium, the leader does not announce (so that $\hat{\theta}(\varnothing|\bar{\mu}) = \theta$) if the stage-1 profits are higher than from announcing off equilibrium ($\hat{\theta}(A|\bar{\mu}) = 1$), that means, if $\tilde{\pi}_G(\theta) \geq \tilde{\pi}_G(1)$ or

$$\big(1+\sigma\,(1-\theta)\big)\,\pi_{GB} \geq \pi_{GB} \tag{B.4}$$

which holds true if $\sigma\,(1-\theta) \geq 0$ and thus for all $\sigma \geq 0$. Also note, the leader is indifferent between $m = A$ and $m = \varnothing$ only if $\sigma = 0$; there are no mixed strategy equilibria for $\sigma \neq 0$. Q.E.D.

Proof of Proposition 4

Proof. The follower's equilibrium strategies are by assumption of $R(1) \geq 0 > R(\theta)$. Moreover, by equation (12) violated, the follower's net benefits from R&D are increasing in $\hat{\theta}$ (Lemma 4) so that $R(1) > R(\theta) > R(0)$.

1. For the leader's strategy, first consider a separating equilibrium, $\mu_G = 1$. The leader's payoffs when it announces (and the follower invests in R&D) are

$$\tilde{\Pi}_G(\hat{\theta}(A|\,(1,0))) = \pi_{GB} + \pi_{GG} + \gamma\lambda - \tilde{\theta}_G\psi_{F|G} = \tilde{\Pi}_G(1)$$

If (off equilibrium) the leader does not announce (and the follower does not invest in R&D because with beliefs $\hat{\theta}(\varnothing|\,(1,0)) = 0$ we have $R(0) < 0$), then her payoffs are:

$$\tilde{\Pi}_G(\hat{\theta}(\varnothing|\,(1,0))) = (1+\sigma)\,\pi_{GB} + \pi_{GG} + \gamma\lambda = \tilde{\Pi}_G(0)$$

with $\gamma\lambda - \tilde{\theta}_G \psi_{F|G} \geq 0$. A separating equilibrium thus exists if $\tilde{\Pi}_G(1) \geq \tilde{\Pi}_G(0)$. Rearranging this condition and using the expressions for $\tilde{\theta}_G$ and $\psi_{F|G}$ yields condition (16) in the Proposition.

Now, consider a pooling equilibrium, where the leader does not announce in equilibrium, $\mu = 0$. On the equilibrium path (observing $m = \varnothing$ and $\hat{\theta}(\varnothing|\,(0,0)) = \theta$), the follower does not invest in R&D. The leader's equilibrium payoffs are:

$$\tilde{\Pi}_G(\hat{\theta}(\varnothing|\,(0,0))) = \big(1 + \sigma\,(1-\theta)\big)\,\pi_{GB} + \pi_{GG} + \gamma\lambda = \tilde{\Pi}_G(\theta)$$

If (off equilibrium), the leader announces, $m = A$, then $\hat{\theta}(A|\,(0,0)) = 1$ and the follower invests in R&D. The leader's off-equilibrium payoffs are:

$$\tilde{\Pi}_G(\hat{\theta}(A|\,(0,0))) = \pi_{GB} + \pi_{GG} + \gamma\lambda - \tilde{\theta}_G \psi_{F|G} = \tilde{\Pi}_G(1)$$

A pooling equilibrium exists $\tilde{\Pi}_G(\theta) \geq \tilde{\Pi}_G(1)$. Rearranging this condition and using the expressions for $\tilde{\theta}_G$ and $\psi_{F|G}$ yields condition (17) in the Proposition.

In either equilibrium, the follower's equilibrium action is the same: he will invest if the leader announces and will not invest if the leader does not announce. The only thing affected is the follower's belief about the type of the leader in case she does not announce, which affects how close to the optimal play he is during stage-1 market interaction.

When the leader announces, there is no uncertainty about her type, accordingly there is no difference between payoffs in separating and pooling equilibrium. Since announcing is the leader's off-equilibrium action in a pooling equilibrium, her equilibrium payoff must be greater. Accordingly, when both equilibria exist, the leader prefers the pooling over the separating equilibrium, and the follower can do no better than to anticipate this preference and to optimally react to it.

Q.E.D.

C Cournot and Bertrand Model

To set up an explicit version of the model we use the classic model developed by Singh and Vives (1984) allowing for horizontal product differentiation and easy comparison of price and quantity competition. The model features a representative consumer with utility function

$$U(q_L, q_F) = (a_L - p_L)q_L + (a_F - p_F)q_F - \frac{q_L^2 + q_F^2 + 2\delta q_L q_F}{2},$$

where q_i denotes output of firm i and p_i its per-unit price, with L identifying the leader and F the follower. $\delta \in (0,1)$ captures the extent of horizontal product differentiation. $\delta = 1$ would be the case of perfect substitutes, which for the usual reason is not defined for the case of Bertrand competition.

Product (i.e., demand-enhancing) innovation is captured by $a_L = a^G > a^B = a_F$,[26] while process (i.e., cost-reducing) innovation implies a difference in marginal production costs. The follower produces at marginal cost c^B, as does the bad leader, while the good leader can produce at $c^G < c^B$.

C.1 Competition in substitutes: Cournot

Inverse demand functions for the above preferences are

$$p_i(q_i, q_j) = a_i - q_i - \delta q_j, \tag{C.1}$$

with $i = \{L, F\}$, $a_F = a^B$, $a_L = \{a^B, a^G\}$ and $a^B < a^G$. Each firm maximises their profit function

$$\pi_i = (p_i - c_i)q_i, \tag{C.2}$$

yielding the following reaction functions:

$$q_L^\theta(q_F) = \frac{a^{\{G,B\}} - c^{\{G,B\}} - \delta q_F}{2}, \tag{C.3}$$

$$q_F(q_L^\theta) = \frac{a^B - c^B - \delta(\theta q_L^G + (1-\theta)q_L^B)}{2}. \tag{C.4}$$

The change in the leader's profit caused by her patent announcement is obtained by taking the difference between equilibrium profit evaluated at $\theta = 1$ and with general θ.[27] (Since $q_L^G > q_L^B$ it could also be obtained directly from substituting the two firms' reaction functions into the leader's

[26] Demand-enhancing innovation may *additionally* have the effect of reducing competition intensity, in which case both firms' profits may increase (Motta, 1993), but this is outside the scope of the present model/section.

[27] This corresponds to the effect of announcing in a pooling equilibrium. In a separating equilibrium, the effect of announcing would be $\pi_L^{\hat{\theta}_1=1} - \pi_L^{\hat{\theta}_1=0}$. The sign of the resulting expression would be the same as the signs derived in the text.

profit function.)

$$\pi_L^{\hat{\theta}_1=1} - \pi_L^{\hat{\theta}_1=\theta} = \frac{1}{4(4-\delta^2)^2}\Bigg(4\Big(2\left(a^G - c^G\right) - \delta\left(a^B - c^B\right)\Big)^2 \\ - \Big(2\Big(2\left(a^G - c^G\right) - \delta\left(a^B - c^B\right)\Big) - \delta^2(1-\theta)\big(a^G - c^G - (a^B - c^B)\big)\Big)^2\Bigg) > 0$$

With Cournot competition (in substitutes), the leader's market profits always increase by announcing her patent, as captured by equation (6). Regarding the follower, the effect of the leader's announcing on his market profits is not required in the analysis of the model. It will implicitly (as part of the welfare function) play a role in the section on welfare below, and it would play a role in the section allowing the follower to have innovated at the start of the game were we to select between different equilibria or even to determine the firms' incentive to engage in R&D. It can be shown to be positive or negative, depending on the values of θ, δ, and the difference between "good" and "bad" firm (i.e., the "size" of the innovation).

C.2 Competition in complements: Bertrand

To model price-setting behaviour we have to derive the demand functions as

$$q_i(p_i, p_j) = \frac{a_i - \delta a_j - p_i + \delta p_j}{1-\delta^2}. \tag{C.5}$$

Profits are still as defined by equation C.2, and reaction functions are:

$$p_L^\theta(p_F) = \frac{a^{\{G,B\}} + c^{\{G,B\}} - \delta(a^B - p_F)}{2}, \tag{C.6}$$

$$p_F(p_L^\theta) = \frac{a^F + c^B - \delta(\theta(a^G - p_L^G) + (1-\theta)(a^B - p_L^B))}{2}. \tag{C.7}$$

The change in the leader's profit caused by her patent announcement is

$$\pi_L^{\hat{\theta}_1=1} - \pi_L^{\hat{\theta}_1=\theta} = \frac{1}{4(4-\delta^2)^2(1-\delta^2)}\left(4\Big[\big(2-\delta^2\big)\big(a^G-c^G\big)-\delta\big(a^B-c^B\big)\Big]^2 - \bigg[\Big(\big(2-\delta^2\big)\big(a^G-c^G\big)-\delta\big(a^B-c^B\big)\Big) + \Big(\big(2-\delta^2\theta\big)\big(a^G-c^G\big)-\big(\delta+\delta^2(1-\theta)\big)\big(a^B-c^B\big)\Big)\bigg]^2\right) < 0$$

With Bertrand competition (in complements), the leader's market profits always decrease by announcing her patent, again as captured by equation (6).

D Legal Statutes

American Inventor's Protection Act (AIPA)

TBA

35 U.S. Code §292 ("False Marking")

(a) Whoever, without the consent of the patentee, marks upon, or affixes to, or uses in advertising in connection with anything made, used, offered for sale, or sold by such person within the United States, or imported by the person into the United States, the name or any imitation of the name of the patentee, the patent number, or the words "patent," "patentee," or the like, with the intent of counterfeiting or imitating the mark of the patentee, or of deceiving the public and inducing them to believe that the thing was made, offered for sale, sold, or imported into the United States by or with the consent of the patentee; or

Whoever marks upon, or affixes to, or uses in advertising in connection with any unpatented article, the word "patent" or any word or number importing that the same is patented, for the purpose of deceiving the public; or

Whoever marks upon, or affixes to, or uses in advertising in connection with any article, the words "patent applied for," "patent pending," or any word importing that an application for patent has been made, when no application for patent has been made, or if made, is not pending, for the purpose of deceiving the public—

Shall be fined not more than $500 for every such offense. Only the United States may sue for the penalty authorized by this subsection.

(b) A person who has suffered a competitive injury as a result of a violation of this section may file a civil action in a district court of the United States for recovery of damages adequate to compensate for the injury.

(c) The marking of a product, in a manner described in subsection (a), with matter relating to a patent that covered that product but has expired is not a violation of this section.

E The model without licensing

This section demonstrates that unprofitability of licensing does not change the model qualitatively. Quantitatively, patent announcement by the leader becomes more frequent when it weakens the follower's R&D incentives, and less frequent when it strengthens the R&D incentives.

E.1 When is licensing unprofitable?

Licensing is mutually unprofitable when the bargaining surplus is negative. Following the proof of lemma 1, the surplus is negative if $2\pi_{GG} < \pi_{GB}$, i.e., precisely when property 2 is violated.

E.2 Follower's R&D Decision Without Licensing

In absence of licensing, the follower's only way of obtaining π_{GG} in period 2 is by own R&D effort. We have to modify equation (9) as follows:

$$\begin{aligned}\pi_F^{nolic}(m,r) = \quad & \hat{\theta}(m|\bar{\mu})\Big[r\big[\tilde{\theta}_G\pi_{GG}\left(1-\gamma\eta\right)\big]+(1-r)\pi_{BG}\Big] \\ & +\Big(1-\hat{\theta}(m|\bar{\mu})\Big)\Big[r\big[\tilde{\theta}_B\pi_{GB}+\Big(1-\tilde{\theta}_B\Big)\pi_{BB}\big]+(1-r)\pi_{BB}\Big]-rK \qquad \text{(E.1)}\end{aligned}$$

Define $R'(\hat{\theta}(m|\mu)) \equiv \pi_F^{nolic}(m,1)-\pi_F^{nolic}(m,0)$, and Lemma 2 remains to hold with R' substituted for R. Lemma 3 is replaced by the following

Lemma 3'.

1. *The leader's announcement $m = A$ deters the follower's R&D investment if $R'(\hat{\theta}(\varnothing|\bar{\mu}) \geq 0 > R'(\hat{\theta}(A|\bar{\mu})) = R'(1)$ or*

$$\frac{K-\Big(1-\hat{\theta}(\varnothing|\bar{\mu})\Big)\tilde{\theta}_B\psi_{F|B}}{\hat{\theta}(\varnothing|\bar{\mu})} \leq \tilde{\theta}_G(1-\gamma\eta)\pi_{GG} < K.$$

2. *The leader's announcement $m = A$ triggers the follower's R&D investment if $R'(\hat{\theta}(\varnothing|\bar{\mu})) < 0 \leq R'(1)$ or*

$$\frac{K-\Big(1-\hat{\theta}(\varnothing|\bar{\mu})\Big)\tilde{\theta}_B\psi_{F|B}}{\hat{\theta}(\varnothing|\bar{\mu})} > \tilde{\theta}_G(1-\gamma\eta)\pi_{GG} \geq K.$$

3. *Unchanged apart from replacing R by R'.*

Lemma 3' differs from lemma 3 in the follower's benefit from doing R&D when the leader announces. Each scenario can be more or less frequent compared to the case with licensing. Net benefit from R&D is greater without licensing if $\tilde{\theta}_G(1-\gamma\eta)\pi_{GG} > \tilde{\theta}_G\psi_{F|G}$, or $\gamma > 2\pi_{GG}/(\eta\ 2\pi_{GG} + (1-\eta)\pi_{GB})$, and smaller else.

E.3 Leader's Announcement in Equilibrium Without Licensing

E.3.1 Scenario 1

Proposition 1'. *Let $R'(\theta) \geq 0 > R'(1)$. The message-innovation game without licensing has the following perfect Bayesian equilibria in pure strategies. The follower invests in R&D if $m = \varnothing$ and does not invest in R&D if $m = A$. Moreover:*

1. *the leader announces and $m = A$ ("separating equilibrium") if*

$$\frac{\sigma}{\tilde{\theta}_G} \frac{\pi_{GB}}{(\pi_{GB} - \pi_{GG})} - (1 - \gamma) \leq \beta; \tag{E.2}$$

2. *the leader does not announce and $m = \varnothing$ ("pooling equilibrium") if*

$$\frac{\sigma(1-\theta)}{\tilde{\theta}_G} \frac{\pi_{GB}}{(\pi_{GB} - \pi_{GG})} - (1 - \gamma) \geq \beta. \tag{E.3}$$

3. *For values of β in between the ranges specified above, the message-innovation game without licensing has a perfect Bayesian equilibrium in mixed strategies.*

Proof. The proof of the two pure-strategy equilibria is equivalent to the proof of propositions 1 in the main text, but the leader's payoffs change as follows. When she announces and the follower does not innovate, the leader obtains

$$\tilde{\Pi}_G^{nolic}(\tilde{\theta}(A|(1,0))) = \tilde{\Pi}_G^{nolic}(\tilde{\theta}(A|(0,0))) = 2\pi_{GB}.$$

The leader's payoff when she does not announce (off equilibrium) and the follower innovates are:

$$\tilde{\Pi}_G^{nolic}(\tilde{\theta}(\varnothing|(1,0))) = \pi_{GB}\left((1+\Sigma) + \tilde{\theta}_G\gamma\eta + \left(1 - \tilde{\theta}_G\right)\right) + \pi_{GG}\tilde{\theta}_G\left((1-\gamma) + \gamma(1-\eta)\right).$$

As in proposition 1, in $\tilde{\Pi}_G^{nolic}(\tilde{\theta}(\varnothing|(1,0)))$, $\Sigma = \sigma$, while in $\tilde{\Pi}_G^{nolic}(\tilde{\theta}(\varnothing|(0,0)))$, $\Sigma = \sigma(1-\theta)$. In each resulting inequality, substitute $1 - \gamma\eta = \beta + (1-\gamma)$ and rearrange accordingly.

For the mixed-strategy equilibrium, replace the leader's payoffs in the proof of proposition 2 as follows: payoff from $m = A$ is $\tilde{\Pi}_G^{nolic}(\hat{\theta}(A|\bar{\mu})) = 2\pi_{GB}$, while payoff from $m = \varnothing$ is

$$\tilde{\Pi}_G^{nolic}(\hat{\theta}(\varnothing|\bar{\mu})) = \tilde{\pi}_G(\hat{\theta}(\varnothing|\bar{\mu})) + \pi_{GB}\left(\tilde{\theta}_G\gamma\eta + \left(1 - \tilde{\theta}_G\right)\right) + \pi_{GG}\tilde{\theta}_G\left((1-\gamma) + \gamma(1-\eta)\right).$$

Q.E.D.

As in the case with licensing, when competition is in substitutes there will only be a separating equilibrium. Comparing inequalities (E.2) and (13), it is immediately apparent that the value on the left-hand side is smaller in the case without licensing (remember that here $\pi_{GB} > 2\pi_{GG}$, and accordingly $\pi_{GB}/(\pi_{GB} - \pi_{GG}) < 2$). Absence of licensing increases the range of parameter values for which the condition for a separating equilibrium holds and analogously decreases the range of values supporting a pooling equilibrium. "Comparative statics" with respect to σ , θ, τ, and η are unchanged. The role of γ is reversed, though: the left-hand side increases more strongly in γ than the right-hand side, associating announcement with a low rather than a high probability of patent grant.

Corollary 1. *Unprofitability of licensing does not qualitatively affect the leader's announcement decision when announcement weakens the follower's R&D incentives. Quantitatively, announcement occurs for a greater parameter range than in the situation with licensing.*

E.3.2 Scenario 2

Proposition 4'. *Let $R(1) \geq 0 > R(\theta)$. The message-innovation game has the following unique perfect Bayesian equilibrium in pure strategies. The follower invests in R&D if $m = A$ and does not invest in R&D if $m = \varnothing$. Moreover:*

1. *the leader announces and $m = A$ ("separating equilibrium") if*

$$-\frac{\sigma}{\tilde{\theta}_G}\frac{\pi_{GB}}{(\pi_{GB} - \pi_{GG})} - (1 - \gamma) \geq \beta; \tag{E.4}$$

2. *the leader does not announce and $m = \varnothing$ ("pooling equilibrium") if*

$$-\frac{\sigma(1-\theta)}{\tilde{\theta}_G}\frac{\pi_{GB}}{(\pi_{GB} - \pi_{GG})} - (1 - \gamma) \leq \beta. \tag{E.5}$$

3. *The equilibrium is not unique for parameter values for which conditions 1. and 2. are both satisfied. A necessary condition for multiple equilibria is $\sigma < 0$. When a pooling equilibrium exists, the leader prefers it to the separating equilibrium.*

As in the case with licensing, when competition is in complements, no separating equilibrium exists. With γ large enough, this case may now extend to competition in substitutes.

Proof. The proof follows the same logic as the proof of proposition 4, but with changed payoffs. Leader's payoff when it announces and the follower innovates:

$$\tilde{\Pi}_G(\tilde{\theta}(A|(1,0))) = \pi_{GB}\left(2 - \tilde{\theta}_G(1 - \gamma\eta)\right) + \pi_{GG}\tilde{\theta}_G(1 - \gamma\eta).$$

Leader's payoff when it does not announce and the follower does not innovate:

$$\tilde{\Pi}_G(\tilde{\theta}(\varnothing|(1,0))) = \pi_{GB}\left(2 + \Sigma\right).$$

In the separating equilibrium, $\Sigma = \sigma$, while in the pooling equilibrium $\Sigma = \sigma(1-\theta)$. In both cases, again substitute β as above.

Pareto-ranking: $\tilde{\Pi}_G(\tilde{\theta}(\varnothing|(0,0))) > \tilde{\Pi}_G(\tilde{\theta}(A|(1,0))) = \tilde{\Pi}_G(\tilde{\theta}(A|(0,0)))$. Q.E.D.

Again we can compare equilibrium conditions without to those with licensing, and again the "comparative statics" are unchanged with the exception of those of γ. Also again, in both cases the left-hand side of the inequalities without licensing are smaller than those in the case with licensing.

Corollary 2. *Unprofitability of licensing does not qualitatively affect the leader's announcement decision when announcement strengthens the follower's R&D incentives. Quantitatively, announcement occurs for a smaller parameter range than in the situation with licensing.*

Without licensing, announcing has the same two effects as with licensing: affecting stage-1 profits via reducing the follower's uncertainty about the optimal response to the leader's strategic variable choice, and affecting expected stage-2 profits via inducing the follower to engage in R&D or not. The effect on stage-1 profits is unchanged, but the effect on stage-2 profits is greater without licensing because the difference between high and low profits is now greater.

In scenario 1 with licensing, the leader gets market profit π_{GG} whether the follower has innovated or not, and gets an additional licensing fee of $\pi_{GB}/2$ if the follower has not innovated around the patent. Announcing increases the likelihood that this additional licensing fee is received (to 1).

In scenario 1 without licensing, the leader's profit difference is due to a change in market profits. She gets π_{GG} when the follower has innovated around her patent and π_{GB} if not, with the associated probabilities unchanged. This difference in profits $\pi_{GB} - \pi_{GG} > \pi_{GB}/2$ is greater than the difference with licensing, $\pi_{GB}/2$. Accordingly, securing the higher stage-2 profits becomes more important to the leader, unless the increase in stage-1 profits achieved by not announcing is substantial (σ is high). An analogous logic applies to scenario 2.

F DTA: Licensing in stage 1

By figure 1, license negotiations only take place at $t = 6$, after the follower's R&D outcome has been observed and, more importantly, after market profits from stage-1 competition have been realised at $t = 3$. Since the leader's innovation exists at $t = 0$ already, the question arises what happens if she is given the opportunity to offer a license to the follower during period 1 already.

The answer depends on whether or not having access to the leader's technology affects the follower's R&D efforts. If R&D efforts are unaffected, then the results for licensing in stage 2 immediately apply to stage 1 as well. The possible market profits are the same as in period 2, therefore Property 2 (licensing is profitable for both parties) and Lemma 1 (equilibrium level of license fees) apply to period 1 as well. Both parties prefer to engage in licensing in period 1 if possible.

However, it may seem reasonable to assume that having access to the technology has *some* positive effect on the follower's own R&D project. This could be in the form of increased probability of success (represented by $\Delta \in [1, 1/\tilde{\theta}_G]$) or as a reduction in the fixed cost of innovation (represented by $\kappa \in (0,1]$). Assuming that the follower engages in R&D irrespective of the leader licensing her technology or merely announcing her patent, the reduced cost of doing R&D is added to the bargaining surplus (while the increased probability of success only affects the occurrence of a zero-sum transfer between the bargaining parties) and hence causes an increase in the equilibrium licensing fees. The bargaining surplus is now $2\pi_{GG} - \pi_{GB} + K(1-\kappa)$, which,equally shared between the two firms, implies a licensing fee of $\lambda^{\kappa} = \frac{\pi_{GB}+K(1-\kappa)}{2}$.

If, instead, the follower engages in R&D only when licensing has made R&D a more attractive option, then the cost of R&D *decrease* the equilibrium licensing fee. The bargaining surplus becomes $\pi_{GG} - \pi_{GB} - K\kappa$, which is positive only for a sufficiently small κ.[28]

Lemma F1. *If licensing during stage 1 does not affect the follower's R&D decision, licensing is profitable for both the leader and the follower. If the follower does R&D only under licensing, licensing is profitable if* $K\kappa < 2\pi_{GG} - \pi_{GB}$.

[28]The size of K in the baseline model is restricted by a maximum of $\pi_{GG} - \pi_{GB}\gamma(1-\tilde{\theta}_G(1-\eta))/2$ instead.

The remaining timeline of the game remains unchanged. The result of patent examination becomes available at $t = 4$, i.e., after stage-1 competition. We continue to assume, therefore, that during period 1 there is no risk of outright infringement or costless imitation by the follower (cf. footnote 19). Before the patent application is published, the information contained is still private knowledge of the leader. During period 1, therefore, the innovation is made available via a binding contract, e.g. involving a non-disclosure agreement. It is only during stage-2 competition that the follower may access and use the innovation without cost in case the patent application is not granted.

F.1 Follower's R&D Decision With Innovation Disclosure

In the setting with a single competitor, licensing during stage 1 is equivalent to the leader announcing here patent. The situation without announcement is unchanged and remains represented by Lemma 2. In case of patent licensing, instead, F's net benefit from R&D investment is

$$R''(1|\text{announcement}) = \left(\tilde{\theta}_G + \Delta\right)\psi_{F|G} - K\kappa$$

Lemma 3 is replaced by the following

Lemma F3.

1. *The leader's announcement $m = A$ deters the follower's R&D investment if $R(\hat{\theta}(\varnothing|\bar{\mu}) \geq 0 > R(\hat{\theta}(A|\bar{\mu})) = R(1)$ or*

$$\frac{K - \left(1 - \hat{\theta}(\varnothing|\bar{\mu})\right)\tilde{\theta}_B\psi_{F|B}}{\hat{\theta}(\varnothing|\bar{\mu})} \leq \tilde{\theta}_G\psi_{F|G} < K\kappa - \Delta\psi_{F|G}.$$

2. *The leader's announcement $m = A$ triggers the follower's R&D investment if $R(\hat{\theta}(\varnothing|\bar{\mu})) < 0 \leq R(1)$ or*

$$\frac{K - \left(1 - \hat{\theta}(\varnothing|\bar{\mu})\right)\tilde{\theta}_B\psi_{F|B}}{\hat{\theta}(\varnothing|\bar{\mu})} > \tilde{\theta}_G\psi_{F|G} \geq K\kappa - \Delta\psi_{F|G}.$$

3. *Unchanged apart from replacing R(1) by R"(1).*

In points 1 and 2 of Lemma F3, the left inequality is unchanged compared to the baseline model as it refers to the case of no announcement. The right-hand side of the right inequalities decreases in κ and Δ, and accordingly scenario 1 becomes less and scenario 2 becomes more frequent. With innovating being more attractive to the follower, some cases that yielded scenario 1 previously will now have F innovate independent of L's disclosure decision, and some cases that had F not innovate will now yield scenario 2 instead.

Lemma F3 characterises the situation assuming that the follower's action is independent of the leader licensing or not. Comparing the inequalities of lemmas 3 and F3, we can distinguish the following scenarios:

Lemma F3'.

1. *The follower does not invest in R&D when the leader announces her patent, irrespective of whether this involves licensing, if*

$$x$$

2. *The follower does invest in R&D when the leader announces her patent, irrespective of whether this involves licensing, if*

$$y$$

3. *The follower invests in R&D only when the leader's announcement involves licensing if*

Lemma F3' correctly captures the follower's actions, but scenario 2 can now arise under two circumstances now. In the first ("scenario 2a"), the follower does R&D also in the absence of licensing, and therefore licensing reduces the cost of R&D, implying an increased licensing fee of $(\pi_{GB} + K(1 - \kappa))/2$. In the second ("scenario 2b"), the follower does R&D only when the leader licenses during stage 1. Licensing therefore increases the cost of stage 1 to the follower as he now "must" pay K, leading to a lower licensing fee of $(\pi_{GB} - K\kappa)/2$.

Returning to the open question of above, licensing will take place in this so-far hypothetical scenario if $K\kappa < 2\pi_{GG} - \pi_{GB}$. From lemma refthm:lemma333' we now know that this scenario will only arise if $K\kappa < (\tilde{\theta}_G + \Delta)\beta\pi_{GB}/2$. Checking if the right-hand side of the former inequality is smaller than that of the latter inequality, we arrive at $(\tilde{\theta}_G + \Delta)\beta < 4\pi_{GG}/\pi GB - 1$, which is always satisfied since the left-hand side is < 1 while the right-hand side is > 1. We can conclude that also in scenario 2 the bargaining surplus is strictly positive and hence licensing will always be profitable.

Above results in a nutshell: the follower will do R&D for a greater range of parameter values when licensing makes R&D easier. Hence, scenario 1 becomes less and scenario 2 more frequent.

Following results in a nutshell: The inequalities that describe the leader's equilibrium actions in scenario 1 are those of proposition 1 with

$$\frac{\text{bargaining surplus}}{\tilde{\theta}_G\pi_{GB}}$$

subtracted from the left-hand side. The inequalities of scenario 2 have the same fraction added to the left-hand side, and the whole left-hand side multiplied by

$$\frac{\tilde{\theta}_G}{\tilde{\theta}_G + \Delta}.$$

In scenario 1, announcement becomes unambiguously more frequent; in scenario 2, the direction of change can go either way.

F.2 Leader's Announcement in Equilibrium When Announcement Weakens the Follower's R&D Incentives (Scenario 1)

As before, the follower does R&D only if the leader does not announce her patent. This implies that in case of licensing (i.e., announcement), having access to the technology does make R&D more attractive by reducing cost and increasing the success probability, but the follower will not make use of this. Hence, he will not be willing to pay a premium for the cost reduction, and the equilibrium licensing fee remains at $\pi_{GB}/2$.

Proposition F1. *Let $R(\theta) \geq 0 > R(1)$. The message-innovation game with licensing in stage 1 has the following unique perfect Bayesian equilibrium in pure strategies. The follower invests in R&D if $m = \varnothing$ and does not invest in R&D if $m = A$. Moreover:*

1. *the leader announces and $m = A$ ("separating equilibrium") if*

$$\frac{2\sigma}{\tilde{\theta}_G} - \frac{2\pi_{GG} - \pi_{GB}}{\tilde{\theta}_G \pi_{GB}} \leq \beta; \tag{F.1}$$

2. *the leader does not announce and $m = \varnothing$ ("pooling equilibrium") if*

$$\frac{2\sigma(1-\theta)}{\tilde{\theta}_G} - \frac{2\pi_{GG} - \pi_{GB}}{\tilde{\theta}_G \pi_{GB}} \geq \beta. \tag{F.2}$$

3. *Unchanged.*

Proof. The above inequalities are obtained using the same profit functions as for proposition 1, but in the case of announcement an additional licensing revenue of $\pi_{GB}/2$ must be added. Q.E.D.

Corollary 3. *Allowing licensing in stage 1 does not qualitatively affect the leader's announcement decision when announcement weakens the follower's R&D incentives. Quantitatively, announcement occurs for a greater parameter range than in the situation without stage-1 licensing.*

F.3 Leader's Announcement in Equilibrium When Announcement Strengthens the Follower's R&D Incentives (Scenario 2)

Announcement can happen under two regimes: either it entices the follower to do R&D, or the follower would have done R&D also absent licensing. The following proposition captures both cases by considering a general licensing fee level λ_1.

Proposition 5. *Let $R(1) \geq 0 > R(\theta)$. The message-innovation game with licensing in stage 1 has the following unique perfect Bayesian equilibrium in pure strategies. The follower invests in R&D if $m = A$ and does not invest in R&D if $m = \varnothing$. Moreover:*

1. *the leader announces and $m = A$ ("separating equilibrium") if*

$$-\frac{2\sigma}{\tilde{\theta}_G + \Delta} + \frac{2(\pi_{GG} - \pi_{GB} + \lambda_1)}{\tilde{\theta}_G + \Delta} \geq \beta; \tag{F.3}$$

2. *the leader does not announce and $m = \varnothing$ ("pooling equilibrium") if*

$$-\frac{2\sigma(1-\theta)}{\tilde{\theta}_G + \Delta} + \frac{2(\pi_{GG} - \pi_{GB} + \lambda_1)}{\tilde{\theta}_G + \Delta} \leq \beta. \tag{F.4}$$

3. *Unchanged.*

Proof. Again, the profit functions are identical to those used in proposition 4, with λ_1 added in the case of announcement. Q.E.D.

When the follower innovates irrespective of the leader's licensing decision, $\lambda_1 = (\pi_{GB} + K(1-\kappa))/2$. When he innovates only after having access to the leader's technology, $\lambda_1 = (pi_{GB} - K\kappa)/2$.

In either case, the fraction containing λ_1 is positive, but its value is greater and therefore licensing more widespread when the follower is willing to pay for the reduction in R&D cost.

Corollary 4. *Allowing licensing in period 1 does not qualitatively affect the leader's announcement decision when announcement strengthens the follower's R&D incentives. Quantitatively, whether announcement occurs more or less often depends on parameter values. Announcement happens more often when it does not affect the follower's R&D decision.*

Additionally allowing licensing in stage 1 has a similar effect as when licensing in stage 2 is unprofitable and does not occur. Here, though, the effect works via an increased difference in stage-1 profits between announcing and not announcing, while the difference in stage-2 profits is the same in both versions of the model.

In scenario 1 without stage-1 licensing, the leader gets π_{GB} by announcing and $\pi_{GB}(1+\sigma)$ by not announcing. In scenario 1 with stage-1 licensing, she gets $\pi_{GG} + \lambda$ by announcing and again $\pi_{GB}(1+\sigma)$ by not announcing. The profit difference with stage-1 licensing is greater than the profit difference without stage-1 licensing if $\pi_{GG} + \lambda > \pi_{GB}$, which always holds by Property 2 and Lemma 1.

This raises the question how patent announcement is affected by switching directly from no licensing to licensing in both stages. This relationship is not as obvious. Consider the conditions for a separating equilibrium in scenario 1, as given by inequalities (13) and (F.1). Define $\phi = \pi_{GB}/(\pi_{GB} - \pi_{GG})$, which in the situation without licensing is < 2. Then, the left-hand side of (13) is smaller than the left-hand side of (F.1) (implying more frequent announcing without licensing) if $\sigma < (\alpha - (1-\gamma)\tilde{\theta}_G)/(2-\phi)$. Whether this inequality holds depends on the parameter values.