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Patent Disclosure in Standard Setting

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Abstract

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Abstract

In this paper we analyze the timing of patent disclosure by a patent holder during the process of industry standard setting. In a non-cooperative model of communication with asymmetric information we endogenize patent holdup to study the effect of patent strength, the productivity of industry standard setting, and a standard setting organization's IPR disclosure rules. We find that late disclosure is more likely in more productive standard setting organizations and in less competitive industries. The enforcement of antitrust laws against deceptive conduct in standard setting organizations results in earlier disclosure.

JEL classification: D71, D82, D83, L15, L41, O32, O34

Keywords: patent holdup; patent disclosure; standard setting organizations; industry standards; disclosure rules; conversation; Bertrand competition.

1 Introduction

Industry or product standards are developed and implemented to facilitate the interoperability of products and increase their value to customers.[1] They also have a social function by improving the rate of diffusion of new technologies[2] and eliminating mis-coordination among producers.[3] Recent empirical research investigates the effects of both collaboration and competition among firms participating in standard setting organizations (SSO) on the success and outcome of this process. Leiponen (2008) and Leiponen and Bar (2008), for instance, show that (social and political) connections are important determinants of the ability to contribute to a standard setting process.[4] On the other hand, conflicting and vested interests—arising from problems of asymmetric information or tensions due to fierce product market competition—can have a significant impact on the process.

This effect is likely to be amplified if the standard incorporates intellectual property (IP) (Weiss and Sirbu, 1990; Farrell and Klemperer, 2007:2026). Feldman, Graham, and Simcoe (2009), for example, document that patents disclosed in SSOs are highly litigated and that the litigation rates are correlated with the business structure of the disclosing firms; Baron and Pohlmann (2010) use a large set of essential-patent declarations to analyze the effect of patent pools on patent disclosure. Such disclosure of IP—especially when delayed—can be used as a strategic variable as it can provide the owner of IP with a bargaining leverage over prospective users of IP—often referred

[1]See, e.g., the discussions of standards and network effects in Scotchmer (2004) or Shapiro and Varian (1998), or the collected works of Stan Liebowitz and Stephen Margolis (Lewin, 2002).

[2]Rysman and Simcoe (2008) show that patents disclosed in SSOs receive up to twice as many citations as other patents in the same sector and conclude that such institutions play a crucial role in leading to a bandwagon process among adopters (especially in the ICT industry).

[3]See the discussion in Farrell and Klemperer (2007:2026f) and the literature cited therein

[4]For an earlier case study on the development of the packet switching standard X.25 in computer communication see Sirbu and Zwimpfer (1985).

to as patent holdup or ambush.[5] In this paper we endogenize the magnitude of patent holdup and study how competition and existence of a valid patent affect the strategic use of disclosure of IP.

Lerner and Tirole (2006) analyze how technology sponsors choose the SSO that maximizes the chances of getting their technologies adopted by final users, and Chiao, Lerner, and Tirole (2007) study (theoretically and empirically) the relationship between IPR disclosure rules[6]—a patent holder's obligation to reveal its intellectual property before a final choice is made—and the level of licensing prices. Yet, little has been written on to what extent the scope for "opportunistic" patent disclosure undermines the work of an SSO, a forum for reaching consensus under competitive and strategic tensions. The work by Simcoe (2008) and Farrell and Simcoe (2009) is a first step in this direction. They highlight the impact of strategic interests on the delay of standard adoption.

In our analysis, we focus on the opportunistic patent disclosure to study how competition and the threat of patent holdup affects the timing of patent disclosure, and eventually the quality of a standard and the timing of its adoption. We present a dynamic model with asymmetric information based on Stein (2008),[7] in which two product-market competitors are engaged in the process of standard setting. They take turns in suggesting new standard components that are outcome of stochastic innovation process. We make two main assumptions: First, ideas for components are complementary insofar as a firm can find a new standard component only if the other firm has suggested a component in the previous round (e.g., Hellmann and Perotti, 2010; Stein, 2008). Second, the model's information structure is asymmetric as the initial standard

[5]See Farrell, Hayes, Shapiro, and Sullivan (2007); Farrell and Shapiro (2008); Ganglmair, Froeb, and Werden (2010); Lemley and Shapiro (2007); Shapiro (2010); Tarantino (2010), among others.

[6]See Annex 2 in http://ec.europa.eu/competition/consultations/2010_horizontals/microsoft_en.pdf.

[7]The model in Hellmann and Perotti (2010) shares many features with Stein (2008). We work with the latter because it can easily be extended to model standard setting with intellectual property.

component is a patent-protected technology and the patent holder must decide when to disclose the patent. Motivated by anecdotal evidence provided by Chiao, Lerner, and Tirole (2007),[8] we assume that the other firm is not aware of the patent before its existence is revealed (see also Kobayashi and Wright, 2009; Shapiro, 2010). The identification of a patent that is relevant to the development of a specific standard imposes huge search costs on the firms participating in an SSO, especially when firms with very large patent portfolios are involved in the discussion.[9] Therefore, unless declared by its holder, the existence of the relevant intellectual property rights is hardly anticipated by firms.

We design our model to capture two key factors that drive a patent holder's decision to disclose. By disclosing early, the patent holder gains from higher productivity of the standardization process, but loses part of her bargaining leverage from patent holdup. This first factor refers to the *benefits* of disclosure of intellectual property. As the patent may contain valuable technical information that provides a deeper understanding of the functioning of a certain technology, disclosure can be fruitfully exploited during the standard setting process. Chiao, Lerner, and Tirole (2007) find that, according to SSO members, by "highlighting the relevant patents or applications, [...] firms felt they were disclosing to competitors valuable information about [...] their future technological strategies." Our model captures this by an increased effectiveness of the standard setting process, meaning an increased probability with which a firm finds a new component or technology for the standard and the other firm agrees to its inclusion.

[8]They report that "due to the [...] complexity of patent portfolios, rivals frequently could not determine 'the needle in the haystack': that is, which patents were relevant to a given standardization effort."

[9]Search costs may turn out to be burdensome even for the patent holders. During a public hearing conducted by the Department of Justice and the Federal Trade Commission in 2007, expert panelists reported that "[c]omplying with different disclosure policies in different SSOs can be costly to IP holders, especially for those with large patent portfolios," and that "if an SSO's disclosure policy is too burdensome, IP holders won't come to the table because of the high cost." (U.S. Dep't of Justice & Fed. Trade Comm'n, 2007:43)

The second factor refers to the *costs* of patent disclosure. The owner of intellectual property of an essential part of the standard can require from other firms producing within the scope of the standard the payment of license fees. The amount of these fees will depend on the strength of the patent (Farrell and Shapiro, 2008) and the extent to which other firms have relied on the standard to be adopted and started manufacturing final products based on the present state of the standard.[10] The patented standard component is therefore locked in by virtue of producers having invested in standard-specific design. We assume that the later the patent holder discloses the patent, the more the patented technology is locked in, and the less likely it is replaced with an alternative.

The existing literature on the ensuing problem of patent holdup—sometimes also referred to as "patent ambush"—in standard setting[11,12] has assumed the *magnitude* of holdup to be exogenous. Patents enable innovators to earn monopoly rents on their innovations. The size of these rents depends on the expected strength or validity of the patent (Farrell and Shapiro, 2008) and the bargaining leverage the innovator obtains from its monopolist position. To our knowledge our model is the first to endogenize

[10] DeLacey, Herman, Kiron, and Lerner (2006) document the long development of the xDSL and IEEE 802.11 standards. More specifically, when discussing the process of standard 802.11n definition (which improved the 802.11g version), DeLacey, Herman, Kiron, and Lerner (2006:13ff) present the case of Belkin, which had been shipping "pre-N" products for over a year before the final specification of the standard was certified.

[11] The patent holdup problem is a greatly debated issue in the law and economics literature, and with dissonant positions. To give two remarkable examples, Lemley and Shapiro (2007) stress the adverse impact of holdup on licensing decisions in industries with complex products, whereas Geradin (2009) claims that the real impact of patent holdup on the correct functioning of standard setting organizations is over-rated. We take a neutral stance and assume that a holdup problem may arise, although its incidence on the standard setting process is endogenous and depends on the timing of patent disclosure.

[12] Remarkably, many of the cases regarding SSOs deal with disclosure issues: In the FTC matters against Dell Computer Corp. (FTC order *Dell Computer Corp., FTC Docket NO. C-3658, 121 F.T.C. 616 (1996)*) and Rambus Inc., *FTC v. Rambus Inc., 522 F.3d 456 (D.C. Cir. 2008)*, the European Commission against Rambus (*"Antitrust: Commission confirms sending a Statement of Objections to Rambus", MEMO/07/330, http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/07/330*), or *Broadcom Corp. v. Qualcomm Inc., 501 F.3d 297 (3d Cir. 2007)*, accusers contended that patentees failed to comply to the disclosure rule of the SSO where the standardization process took place.

patent holdup in standard setting. We assume patent strength to be given, however, view the bargaining leverage as being contingent on whether or not the patented technology is included in the standard. With early disclosure a suitable alternative for the patented-protected component can be found without discarding the entire standard as the standard setting process is still at an early stage. Delaying disclosure locks in the patent-protected component as finding a suitable alternative becomes less likely. In combination with producers being locked in by having invested in standard-specific design, the innovator obtains a higher bargaining leverage over producers the later it discloses the patent.

For the baseline model we first consider an SSO with an IPR policy, i.e., disclosure rule, that requires the patent holder to disclose the patent to the SSO. Failure to do so results in a waiver of IP rights. This means that if by the end of the standard setting process the patent is not disclosed, the patent holder loses its bargaining leverage over manufacturers that sell standard-compliance products.[13] We find two sets of results:

First, a valid patent is a necessary condition for the patent holder to delay disclosure, i.e., not disclose at the beginning of the standard setting process. A valid patent is not sufficient, though. The *productivity* of the standardization process, i.e., the success probability of innovation, meaning the probability with which firms find further components to add to the standard, is another key factor. If in the absence of disclosure the standard setting process is relatively productive, the patent holder is willing to

[13]For example, see the European Commission's press release on the Rambus case (*"Antitrust: Commission accepts commitments from Rambus lowering memory chip royalty rates", IP/09/1897, http://europa.eu/rapid/pressReleasesAction.do?reference=IP/09/1897*) and the United States Court of Appeals for the Federal Circuit decision on *Qualcomm Inc. v. Broadcom Corp., Docket Number 07-1545. Nos. 2007-1545, 2008-1162. http://caselaw.findlaw.com/us-federal-circuit/1150919.html ("[W]e agree with the district court that, '[a] duty to speak can arise from a group relationship in which the working policy of disclosure of related intellectual property rights ('IPR') is treated by the group as a whole as imposing an obligation to disclose information [...].' [...] In these circumstances, we conclude that it was within the district court's authority [...] to determine that Qualcomm's misconduct falls within the doctrine of waiver. [...] remand with instructions to enter an unenforceability remedy limited in scope to any [standard]-compliant products.")*.

forego the gains from a rise in productivity and obtain a higher bargaining leverage instead. A small effect on productivity of the process implies a delay of disclosure.

For the second set of results, we disentangle the effect of the degree of product market competition on the functioning of the standard setting process and the timing of disclosure. We show that in a highly competitive industry collaborative standard setting cannot be sustained. Intuitively, strong competitive pressures impair the agents' incentives to cooperate on the development of a standard. For an intermediate level competition the procedure of standard development becomes viable again and disclosure is not strategically delayed. Moreover, lower levels of competition render disclosure more and more profitable. The intuition is that if competitive pressures are fierce, the gains from holdup cannot be large. Tough competition implies that firms profits are modest, and so are the rents that can be extracted from competitors via licensing. Conversely, as competition softens, larger product market profits give a strong incentive to delay disclosure so to recoup higher licensing fees.

When we relax the assumption that patent holders waive their IP rights when not disclosing the patent during the standard setting process—we refer to this case as *ex-post disclosure*—we find that patent disclosure is delayed even more. The underlying story is simple. The costs of not disclosing the patent, particularly, the threat of losing one's bargaining leverage when missing the window of opportunity, are lower with an SSO's IPR policy that does not sanction ex-post disclosure.

Our results contribute not only to the discussion of strategic patent disclosure and holdup in standard setting, but has implications for the general literature on knowledge sharing and diffusion (Anton and Yao, 2002, 2004; Haeussler, Jiang, Thursby, and Thursby, 2009; Hellmann and Perotti, 2010; Stein, 2008; von Hippel, 1987). von Hippel (1987), for instance, in an early contribution studies the problem of technical know-how trading among technicians of competing firms and shows, by means of case studies, that cooperative communications between competitors can take place, however, such conversations are not sustainable when very harsh competition is at work.[14] We deliver the analogous result that tough competition impedes firms' discussions and prevents collaborative standard setting. With a focuse on the complementarity of information[15] Haeussler, Jiang, Thursby, and Thursby (2009) build a model of knowledge diffusion among academic scientists. Their model shares with ours the feature that complementary information is needed to solve a problem and that such information is exchanged among competing agents. They assume that each agent can quit the info sharing game with its own solution to the problem, whereas we rule this out; a successful standard setting process requires collaboration of all parties involved.

The structure of the paper is as follows: In Section 2 we introduce our extension of the model by Stein (2008). In Section 3 we define the first best outcome and show that in cooperative equilibrium a standard setting process cannot be sustained if competition is too fierce. In Section 4 we analyze the non-cooperative equilibria of our baseline model and consider the extension of ex-post disclosure in Section 5. In Section 6 we discuss a parameterized version of the model. We conclude in Section 7. The formal proofs of the results are relegated to the Appendix.

2 Basic Model

We draw on the basic setup in Stein (2008) and add disclosure of IPR to the model. There are two players, A (she) and B (he), that engage in a process of industry standard definition by means of exchanging ideas and technologies. They take turns with A moving at stages $t = 1, 3, 5, \ldots$ and B moving at stages $t = 2, 4, 6, \ldots$. At each stage,

[14] von Hippel (1987) makes the example of the aerospace industry, where firms competing for an important government contract report not to trade information with rivals.

[15] See also Hellmann and Perotti (2010) or Stein (2008).

the player to move has an opportunity to develop a new technology χ_t (i.e., candidate component of the industry standard).

2.1 Information Structure

At $t = 1$, player A has access to an initial, patent-protected technology χ_1. At stage $t = 1$ and any future odd stage, she has three options: She can (1) *stop* the process (stay quiet and reveal neither the technology nor the patent), (2) *disclose* (reveal both the technology and the fact that it is patent-protected), or (3) *continue* the process (communicate the technology to B but keep the fact that it is patent-protected to herself).[16] These actions imply the following for the structure of the standard setting process.

1. If A *stops* at any odd t, player B cannot develop χ_{t+1} and the game ends. This assumption embeds a strong form of complementarity into the production function for components of the standard. A useful new technology and component of the standard can be produced by a firm only if there is access to a prior technology.

2. If A *discloses* at any odd t, meaning revealing the existence of the patent on technology χ_1 and communicating the new technology χ_t, firm B will with probability q develop a new technology and standard component χ_{t+1} at $t + 1$. If B fails, with probability $1 - q$, the game stops. If successful, player B can either *continue* by truthfully revealing technology χ_{t+1}, after which it is A's turn in $t + 2$; or *stop*. At $t + 2$, firm A will have disclosed and is left with the decision to either *stop* or *continue*.

3. If A *continues* at any odd t and has disclosed at an earlier stage, the game continues as described above. If A has not yet disclosed the patent and at t

[16] Note that A can choose not to disclose the patent at $t = 1$ but reconsider her decision at $t = 3, 5, \ldots$

decides to continue and therefore keep its existence to herself, firm B develops a new technology and standard component χ_{t+1} with probability $p < q$.

The structure of the game is depicted in Figure 1.[17] The process continues until one player fails to produce a new component or decides to *stop*. We assume that B is not aware of the possibility that the initial component is patent-protected (Chiao, Lerner, and Tirole, 2007; Kobayashi and Wright, 2009; Shapiro, 2010). This implies that, as long as A has not disclosed her patent, B will at any even t anticipate that both parties have at $t+1, t+2, \ldots$ a probability p of finding a new component for the standard.

[FIGURE 1 ABOUT HERE]

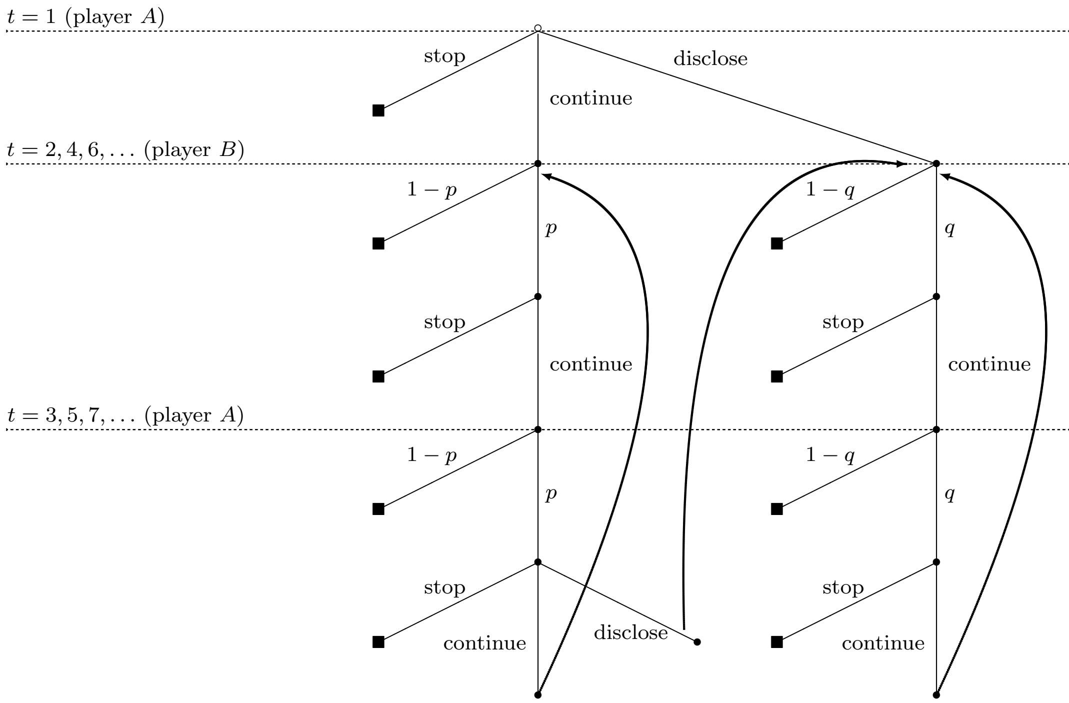
2.2 Payoffs

The longer firms communicate and therefore the more components they add to a standard—let that number of communication rounds and standard components be denoted by n_S—the better the standard eventually becomes. We follow Stein (2008) and design the parties' payoff functions trying to provide the specific competitive setting in the product market as well as introducing to the model the main forces that characterize the functioning of SSO. Market profits realize only after the standardization process is brought to an end and the standard adopted. The timing of conversation and competition is depicted in Figure 2.

[FIGURE 2 ABOUT HERE]

[17] The left arm of this game tree depicts the game structure in Stein (2008), the right arm represents our extension of his model, accounting for intellectual property in the communication of a standard setting process.

Figure 1: Conversation Game with Patent Disclosure

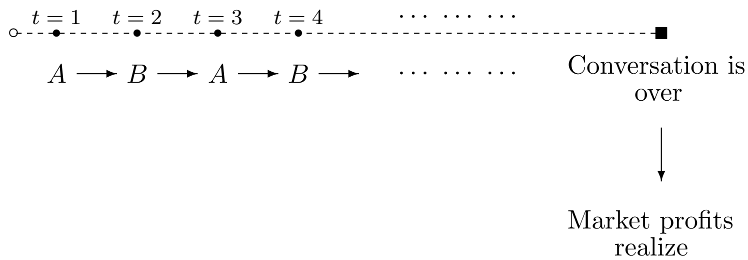


Standard Setting Organization's Rules: The SSO of the baseline model has two main rules: The *disclosure rule* and the *licensing rule*. The disclosure rule prescribes that A must declare relevant IPRs before the conversation on the composition of the standard is over and the standard technology is adopted on the product market. In line with the legal evidence of courts imposing waivers on firms that have tried to enforce undisclosed IP, the rule on the licensing regime prescribes that A can set a license fee only if she discloses the patent before the end of the standardization process.[18]

Product market competition: The higher the number of components, n_S, and the higher the quality of the standard, the lower the costs the parties incur in production. More specifically, having access to an n_S-standard, the parties can manufacture the

[18]In the extension with ex-post disclosure, we will relax this assumption and assume that A can levy a fee even if she declares her IPRs after the end of the conversation with B.

Figure 2: Timing of Standard Setting and Competition



product at cost $(1 - h(n_S))$. Here, $h(n_S)$ is an increasing function, with $h(0) = 0$ and $\lim_{n_S \to \infty} h(n_S) = 1$, that captures the total cost savings associated with n_S components. Also, a party that develops a new technology but decides not to communicate it manufactures the product at cost $(1 - h(n_S + 1)) < (1 - h(n_S))$ and has therefore a cost advantage over its rival.

We assume that players A and B each face a market of unit mass and that all customers into the market have a reservation value of one. Moreover, there is a fractional overlap of size θ in A's and B's customer bases, with $0 < \theta < 1$. In other words, A and B have a monopoly on a fraction $(1 - \theta)$ of their customers, but compete for the remaining fraction θ. The products are otherwise undifferentiated and competition is à-la-Bertrand.

The effect of shading the existence of a relevant patent on firms' payoffs is driven by two factors.

Productivity: When A discloses to B the existence of the patent, the probability that either party in subsequent periods finds new components for the standard is higher than when the patent is hidden, $q > p$. The standardization process becomes more productive, creating a shared interest in communicating the patent as soon as possible.

Holdup: The holdup problem of manufacturers who employ patent-protected technologies face is characterized as follows: If patent-holder firm A does not sell a license for the initial patent-protected technology, χ_1, then manufacturer B infringes in both his monopoly market as well as in the competitive market. This threat gives player A a bargaining leverage that maps into the license fee the parties will negotiate once the standard has been adopted and production commences.

Let $\sigma \in (0, 1)$ be the fraction of B's profits player A can extract by means of license fees. It depends on two factors: (1) Let $\tau \geq 1$ the timing of disclosure. As more and more components χ_t are added to the standard, the initial technology χ_1, upon which the standard is built, becomes more essential and the degree of lock-in increases. This implies that the later firm A discloses the patent, the more difficult it becomes to find an adequate substitute for the patented technology. Also, the longer the standard setting process takes the greater the degree to which manufacturers are locked in, having relied on a non-proprietary standard. (2) Let $\alpha > 0$ denote the strength of the patent. Suppose no adequate substitute can be found for the patented technology, then player A's bargaining leverage will eventually depend on how weak or strong the patent is (Farrell and Shapiro, 2008). We assume that firm A's profit share, $\sigma = \sigma(\alpha, \tau)$, is continuous and increasing in α and τ with $\sigma(0, \tau) = 0$, $\sigma(\alpha, 1) = 0$ and $\lim_{\tau \to \infty} \sigma(\alpha, \tau) = \alpha$.

A measure for the quality of the standard is its number of components, n_S. If the standardization process stops because either firm fails to find a new component, then both firms have access to the same information and $n_A = n_B = n_S$, where n_i is the number of components firm i is aware of. Alternatively, if party i finds a new component but decides to stop the standardization process without revealing it, then $n_i = n_S + 1 > n_S = n_{-i}$. That firm then has an advantage over its competitor because it can manufacture the product at a lower price, $1 - h(n_s + 1) < 1 - h(n_S)$. Put together, the assumptions above yield payoffs of

$$U_A = (1-\theta)\, h(n_A) + \theta \max\{0, h(n_A) - h(n_B)\} + \sigma(\alpha,\tau) U_B \tag{1}$$

for player A and

$$U_B = [(1-\theta)\, h(n_B) + \theta \max\{0, h(n_B) - h(n_A)\}]\,(1-\sigma(\alpha,\tau)) \tag{2}$$

for player B. The first part of equation (1) reflects the fact that for a fraction $(1-\theta)$ of her customers, A is a monopolist and charges the full reservation value of one; with costs of $(1-h(n_A))$. Her profits per customer are thus $h(n_A)$. On the remaining fraction θ of her customers, where A's and B's consumer bases overlap, Bertrand competition implies that A makes a profit only if her costs are strictly below those of B (*mutatis mutandis* for B in equation (2)). The third term in (1) reflects the fact that by enforcing her IPR, player A can extract a share $\sigma(\alpha,\tau)$ of B's profits.

3 First Best and Cooperative Equilibrium

In a first-best world, firm A discloses her patent at $t = 1$ and both A and B communicate their respective ideas for standard components until they fail to find further ideas. The intuition for this is straightforward. As more components increase the quality of the standard and lower the costs of production, communication is socially desirable. Disclosure of the patent increases the productivity of this process.

A first question is whether the first-best outcome can be implemented in a cooperative equilibrium. The parties' joint payoffs are

$$U^C = \begin{cases} U_A + U_B &= 2\,(1-\theta)\,h(n_A) & \text{if } n_A = n_B \\ U_i + U_j &= h(n_i) + (1-2\theta)\,h(n_j) & \text{if } n_i > n_j \end{cases} \tag{3}$$

In the latter case firm $i = A, B$ has not continued and revealed an idea. For $\theta = \frac{1}{2}$, the two expressions for U^C are equivalent. For any $\theta > \frac{1}{2}$, however, the joint payoffs from (cooperatively) not continuing (so that $n_i > n_j$) are higher than from continuing. We show in the following proposition that disclosure and communication of ideas is not part of a cooperative equilibrium if θ is sufficiently high. In other words, in a highly competitive industry, collaborative standard setting cannot be sustained.

PROPOSITION 1 (Cooperative Equilibrium)**.** *If competition is too high (for sufficiently high values of θ) there is no communication in the cooperative equilibrium.*

The formal proof of this result is relegated to the appendix. For a parametric example, suppose $h(n) = 1 - \beta^n$ with $0 < \beta < 1$. The joint payoffs from stopping the process are strictly larger than from continuing if

$$2\,(1-\theta)\left[1 - \frac{\beta^t\,(1-q)}{1-\beta q}\right] < 2\,(1-\theta) - (1+\beta-2\theta)\,\beta^{t-1}. \tag{4}$$

This greatly simplifies to

$$\frac{1+\beta q}{2} < \theta. \tag{5}$$

For the remainder of this paper we restrict attention to sufficiently low degrees of competition, $\theta < \frac{1+\beta q}{2}$. If communication for all t cannot be implemented in a cooperative equilibrium, it will not be implementable in a non-cooperative equilibrium, which is what we analyze in the next section.

4 The Case of Ex-Ante Disclosure

The analysis of non-cooperative equilibria demonstrates how patent disclosure and the scope for holdup affect the firms' incentives to communicate in a standard setting process. We proceed as follows: We first shed light on their incentives to continue communication after the patent has been disclosed[19] and then derive conditions for player A to disclose her patent.

4.1 Post-Disclosure Communication

Suppose player A disclosed the patent at stage τ so that success probability (of finding a new component) is q. We first consider the case for B and then turn to player A.

If at $t \geq \tau + 1$, B *continues* and the game moves along the equilibrium path, i.e., always continue, until either A or B fail to find a new component, player B's expected payoffs are given by

$$\mathrm{E}_t U_B(continue@t|\tau) = (1 - \sigma(\alpha, \tau))\,(1 - \theta)\,H(t|q)$$

where

$$H(t|q) = \sum_{i=0}^{\infty} q^i\,(1-q)\,h(t+i). \tag{6}$$

The intuition behind the expression in (6) is as follows: With probability $(1 - q)$, there will be no further ideas after time t, so the standard has t components with a total cost-cutting value of $h(t)$ for both parties; with probability $q\,(1 - q)$, there will be exactly one further idea after t, so the standard has $t + 1$ components with a total cost-cutting value of $h(t + 1)$; with probability $q^2\,(1 - q)$ there are exactly two further components, and so forth. By contrast, suppose that player B considers deviating from

[19] This is analogous to the steps in Stein (2008) but for probability $q > p$ and sharing rule $\sigma(\alpha, \tau)$ of B's profits.

the equilibrium strategy, i.e., *stop* at stage t. His payoffs in this case are equal to

$$U_B(stop@t|\tau) = (1 - \sigma(\alpha, \tau)) \left[h(t) - \theta h(t-1) \right].$$

This expression reflects the fact that if B stops, he keeps idea χ_t to himself and has therefore a production cost advantage over A. This allows him to not only earn a profit of $(1-\theta)\, h(t)$ in the monopoly market, but also a profit of $\theta \left[h(t) - h(t-1) \right]$ in the competitive market.[20] Because of A's patent holdup, firm B keeps only a fraction $(1 - \sigma(\alpha, \tau))$ of his profits.

For player B to always *continue* the conversation, $\mathrm{E}_t U_B(continue@t|\tau) \geq U_B(stop@t|\tau)$ must hold for all values of $t > \tau$. This condition is satisfied if and only if

$$\frac{H(t|q) - h(t-1)}{h(t) - h(t-1)} \geq \frac{1}{1-\theta}. \tag{7}$$

We derive player's A condition to *continue* the communication analogously. If at $t \geq \tau + 2$, A *continues* and the game moves along the equilibrium path until either A or B fail to find new components, player A's expected payoffs are given by

$$\mathrm{E}_t U_A(continue@t|\tau) = (1-\theta)\,(1 + \sigma(\alpha, \tau))\, H(t|q). \tag{8}$$

The expression is the same as for player B, except that instead of "paying" a fraction $\sigma(\alpha, \tau)$, player A receives a fraction $\sigma(\alpha, \tau)$ of B's profits. Now, suppose that player A considers deviating from her equilibrium strategy, i.e., *stop* at stage t. In this case, her payoffs are

$$U_A(stop@t|\tau) = h(t) - \theta h(t-1) + (1-\theta)\, \sigma(\alpha, \tau) h(t-1). \tag{9}$$

[20] In the Betrand game, B underbids A by offering a price $1 - h(t-1)$. His production costs are $1 - h(t)$

It reflects her monopoly and competition profits as well as her share from B's monopoly market profits.[21] For player A to always *continue* the process, $\mathrm{E}_t U_A(continue@t|\tau) \geq U_A(stop@t|\tau)$ must hold for all values of $t > \tau$. This is satisfied if and only if

$$(1 + \sigma(\alpha, \tau)) \frac{H(t|q) - h(t-1)}{h(t) - h(t-1)} \geq \frac{1}{1-\theta}. \tag{10}$$

We can conclude from conditions (7) and (10) that, after disclosure, if $\sigma > 0$, player A's incentives to *continue* the standardization process are stronger than player B's. Her condition to continue is therefore never binding.[22] This implies that once the patent has been disclosed, whether or not continuing the standard setting process can be sustained in equilibrium does not depend on the threat of patent holdup as (7) is independent of σ.

4.2 Patent Disclosure

We now turn to firm A's decision to disclose the patent. In the cooperative equilibrium, she reveals the information about the patent right away to (jointly) benefit from increased productivity of the standard setting process. For the main results of this paper, we ask the following: Does firm A ever have an incentive to delay disclosure? And if so, what are the conditions for such delayed disclosure?

We have assumed that firm B is not aware of the possibility of a patent. He has incomplete knowledge of player A's action set as he does not anticipate player A's

[21] Note that in case of A stopping and not communicating the last component χ_t so that the standard consists of only $t-1$ components, B's competition profits are equal to zero.

[22] Equation (7) is binding. For the parametric example in Section 3 (which uses a functional form for $h(\cdot)$ employed by Stein (2008)), *continue* is the non-cooperative equilibrium strategy for both firms if $\beta q \geq \theta$. The condition for sustaining a non-cooperative equilibrium is more restrictive than for a cooperative equilibrium, $\theta < \frac{1+\beta q}{2}$.

choice to *disclose*. By Stein (2008), firm B's pre-disclosure condition to continue is

$$\frac{H(t|p) - h(t-1)}{h(t) - h(t-1)} \geq \frac{1}{1-\theta} \tag{11}$$

with $H(t|p)$ given as in equation (6) for probability p instead of q. Because $q > p$, for a given t, $H(t|q) > H(t|p)$, so that, for $q \geq p$ and $\alpha \geq 0$, condition (11) implies condition (7), and condition (7) implies condition (10).

Condition (11) gives rise to two cases that we need to consider: The first, which we call "unconstrained disclosure" and analyze below, is the case when (11) holds. This means if firm A decides to *continue* communication but not *disclose* the patent, then pre-disclosure communication is sustainable as an equilibrium, as firm B will *continue* the process. The second case, which we call "constrained disclosure," is when condition (11) is violated. This means that firm B does not have an incentive to continue prior to disclosure. Firm A's decision is thus constrained by the anticipation of B stopping the process. As we will see later, A can salvage the standard setting process by disclosing early on.

4.2.1 Unconstrained Disclosure

At every odd stage t, player A has to decide[23] whether to *disclose* right away, so that $\tau = t$, and realize expected payoffs

$$\mathrm{E}_t U_A(disclose@t) = (1-\theta)\,(1+\sigma(\alpha,t))\,H(t|q), \tag{12}$$

[23] Note that *stop*ping is dominated. We assume that (11) holds. Moreover, (11) implies (7) implies (10), where the latter implies that after disclosure firm A's *continue* dominates firm A's *stop*. Because $\sigma = 0$, prior to disclosure firm A's payoffs from stopping are lower than after disclosure, so that stopping is less attractive and condition (10) sufficient for pre-disclosure stopping to be dominated.

or postponing disclosure, meaning *continue* at t and *disclose* at $t+2$ with expected payoffs

$$\begin{aligned}\mathrm{E}_t U_A(\mathit{disclose@}t+2) &= (1-\theta)\left[(1-p)\,h(t)+p\,(1-p)\,h(t+1)\right]+ \\ &\quad (1-\theta)\,p^2\,(1+\sigma(\alpha,t+2))\,H(t+2|q). \qquad (13)\end{aligned}$$

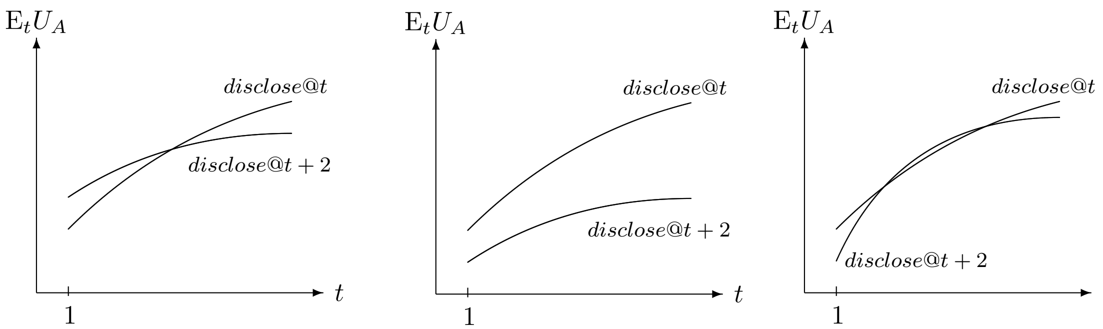
Firm A faces the following trade-off: On the one hand, the continuation value after disclosure increases the later disclosure takes place, indeed $\sigma(\alpha,t)<\sigma(\alpha,t+2)$ and $H(t|q)<H(t+2|q)$. On the other hand, by postponing disclosure one round, A loses the gains associated with disclosure at t and $t+1$, characterized by the possibility to expropriate a fraction $\sigma(\alpha,t)$ of B's profits at an increased probability $q>p$. The expected value at t of the gains from disclosure at $t+2$ are discounted by p^2, which is the probability the standardization process reaches stage $t+2$.

Provided a regularity condition, discussed below, in Proposition 2 we provide a simple necessary and sufficient condition for firm A to delay disclosure to a later period, so that $\tau>1$. We also show that firm A will eventually want to disclose the patent—τ is finite—meaning that unless the process is terminated due to either firm's failure to find a new component, the patent will always be disclosed. The simple condition states that if at $t=1$ firm A's expected payoffs from postponing disclosure one round to $t=3$ are at least as high as from disclosing right away, i.e., if

$$\mathrm{E}_1 U_A(\mathit{disclose@}3) \geq \mathrm{E}_1 U_A(\mathit{disclose@}1), \qquad (14)$$

then disclosure will be delayed at least one round. We reformulate firm A's disclosure problem as an optimal stopping problem and, using results provided by Stokey and Lucas (1989), we show that a stopping rule exists. Such a case is depicted in panel

Figure 3: Expected Payoffs From Delaying Disclosure: Three Cases



(a): Disclosure at $\tau > 1$ *(b): Disclosure at* $\tau = 1$ *(c): Irregular*

(a) of Figure 3. We plot the graphs for expected payoffs at t from disclosure at t and disclosure at $t + 2$ over time.

[FIGURE 3 ABOUT HERE]

Condition (14) above is a sufficient condition for delayed disclosure. Consider panels *(b)* and *(c)* of Figure 3 when the condition is violated. Because in the limit the expected payoffs from delaying are strictly smaller than from disclosing, the two graphs for expected payoffs (disclosure at t and disclosure at $t + 2$) never intersect or intersect twice.[24] In the former case, the simple condition is not only sufficient for delayed disclosure but also necessary, because if it does not hold firm A will disclose right away as her expected payoffs will always be strictly higher than the expected payoffs from delaying. In the latter case, we cannot rule out that, although disclosing right away is the dominant action at $t = 1$, firm A waits until a point when delaying is dominant (as the graph for disclosure at $t + 2$ lies above the graph for disclosure at t). We rule out this case by assumption of a regularity condition. The formal proof of the proposition is relegated to the appendix.

[24]The two graphs could be tangents or intersect more than twice. For the argument, cases are of no relevance.

PROPOSITION 2. *Let* $\mathrm{E}_t U_A(disclose@t)$ *and* $\mathrm{E}_t U_A(disclose@t{+}2)$ *intersect at most once. If*

$$\mathrm{E}_1 U_A(disclose@3) \geq \mathrm{E}_1 U_A(disclose@1) \tag{15}$$

then firm A delays disclosure. There exists a finite disclosure date $\tau > 1$*. If (15) does not hold, the patent is disclosed at the outset of the standardization process and* $\tau = 1$*.*

In the following two propositions we refine the existence result of an optimal stopping rule. We provide the formal proofs in the appendix.

In Proposition 3 we show that the presence of valid intellectual property and ensuing threat of patent holdup is a necessary condition for the delay of disclosure. This seems tautological. Without intellectual property there is no intellectual property to disclose. The crucial point is that intellectual property is valid in the sense that (i) it can be enforced, meaning that it is not invalidated by means of an SSO's IPR rules or antitrust agencies' intervention, and (ii) it is "strong" enough. Without the prospect of a bargaining leverage arising from IPR, firm A has no incentive to jeopardize the productivity of the standard setting process by not revealing.

PROPOSITION 3. *Let* $q > p > 0$*. Enforced intellectual property and ensuing patent holdup is a necessary condition for the delay of patent disclosure, i.e.,* $\alpha > 0$ *so that* $\sigma(\alpha, t) > 0$ *for all* $t > 1$*.*

The presence of valid intellectual property is a necessary condition for delayed disclosure. However, it is not sufficient. We show in Proposition 4 that, given $\alpha > 0$, there is a lower bound $\bar{p} < q$ for the pre-disclosure success probability p (a measure for the pre-disclosure productivity of the standard setting process) such that condition (15) holds and disclosure is delayed for all $p \geq \bar{p}$; and (15) is violated for all $p < \bar{p}$ so that $\tau = 1$.

PROPOSITION 4. *Let $\alpha > 0$ and $q > 0$. If the pre-disclosure success probability p is not too low, i.e., for $\bar{p} \leq p < q$ with $\bar{p} > 0$, condition (15) holds and disclosure of the patent is delayed.*

For the remainder of this section we assume that the pre-disclosure success probability is sufficiently high so that the patent is delayed, $p \geq \bar{p}$ and $\tau > 1$. By Proposition 2, the disclosure stage τ is such that the expected payoffs from disclosure in t in equation (12) are at least as high as the expected payoffs from disclosure in $t + 2$ in equation (13) for all $t \geq \tau$ and strictly smaller for all $t < \tau$. In Proposition 5 we provide comparative statics for firm A's propensity to delay disclosure.

PROPOSITION 5. *The patent holder is more inclined to delay disclosure of her patent the higher the pre-disclosure success probability p is. The strength of the patent, α, has an ambiguous effect on the propensity to disclose the patent. If the effect of patent strength on the patent holder's bargaining leverage is sufficiently increasing with delayed disclosure, so that*

$$\frac{\sigma_\alpha(\alpha, \tilde{t})H(\tilde{t}|q)}{\sigma_\alpha(\alpha, \tilde{t}+2)H(\tilde{t}+2|q)} < p, \tag{16}$$

then patent strength α has a delaying effect on patent disclosure.

In Proposition 3 we showed that the existence of enforceable IPRs is a necessary condition for delay of disclosure, so that $\tau > 1$ and the patent holdup problem arises; in Proposition 4 we provided a sufficient condition for delayed disclosure. Whether or not these two factors of of the standard setting process—patent strength α and the pre-disclosure productivity of the process, p—have a positive effect on the patent holder's propensity to delay disclosure, is discussed in Proposition 5. The results for the latter are clear, the impact of patent strength, however, is ambiguous and will eventually depend on the bargaining technology determining the shape of σ. We come back to this point, when we discuss a parameterized version of the model.

4.2.2 Constrained Disclosure

We now analyze the case when prior to disclosure a communication equilibrium cannot be sustained because (11) is not satisfied for all t. This means that if player A were to *continue* at some t, player B would *stop* at $t + 1$.

PROPOSITION 6. *Let condition (11) be violated for some* $t \geq 1$.

1. *If condition (7) is violated for some* $t > \tau \geq 1$, *then player* A *will* stop *at* $t = 1$.
2. *If condition (7) holds for all* $t > \tau \geq 1$, *then player* A *will* disclose *at* $t = 1$, *and the process continues until one of the parties fails to come up with a new standard component.*

There are three main implications to take away from Proposition 6. *First*, for a high degree of competition, so that (7) is violated and post-disclosure communication cannot be sustained, the standardization process is never initiated. Consider the parameterization introduced above. For all $\frac{1+\beta q}{2} \geq \theta > \beta q$, the parties jointly benefit from standardization but, in a noncooperative game, cannot sustain the process.

Second, for degrees of competition that allow for the process to be initiated, $\beta q \geq \theta > \beta p$, we observe immediate disclosure. This means player A forsakes her rent-seeking possibilities. The intuition for the last result is straightforward. For high degrees of competition, player B's monopoly profits are relatively low. Because player A can extract rents only from B's monopoly profits—the parties' profits from the market on which they compete are tiny or zero—if competition is fierce the gains from holdup are small, and more than outweighed by the gains form disclosing right away to increase the efficiency of the standardization process.

Third, not surprisingly, a very inefficient pre-disclosure process will provide little incentive for player A to delay disclosure. As we can conclude from Proposition 6, a sufficiently high success probability, $p \geq \frac{\theta}{\beta}$, so that condition (11) holds, is necessary for player A to delay disclosure and engage in rent-seeking or holdup activities.

5 Ex-Post Disclosure

In this extension of the baseline results we relax the assumption that firm A, when not disclosing the patent prior to the end of the standard setting process, waives her IPR so that $\sigma = 0$. This means, if the patent has not been disclosed when firm either A or B at stage t *stops* communication, A can disclose ex post and $\sigma = \sigma(\alpha, t)$. Likewise, when the parties *continue* the conversation at t but either fails to find a component for the standard, $\sigma = \sigma(\alpha, t)$. Moreover, we focus on the case of unconstrained disclosure, so that (11) holds.

The parties' post-disclosure incentives are unaffected. Pre-disclosure payoffs for firm A, however, will change. They are

$$\widehat{U}_A(stop@t) = U_A(stop@t|\tau) \tag{17}$$

in equation (9) if *stop*. Firm A's pre-disclosure payoffs from *stop* are the same as the post-disclosure payoffs in the baseline mode; indeed, A can now enforce her patent even after the process ends. For the same reason, A's payoffs are

$$\mathrm{E}_t\widehat{U}_A(continue@t) = (1-\theta)\,\widehat{H}(t|p), \tag{18}$$

if *continue* with

$$\widehat{H}(t|p) = \sum_{i=0}^{\infty} p^i \,(1-p)\, h(t+1)\,(1+\sigma(\alpha, t+i))\,. \tag{19}$$

We show in Lemma 1 that if firm B's pre-disclosure communication condition in equation (11) holds, meaning that as long as the patent is not disclosed, firm B will not stop communication, then for firm A to *stop* is dominated by to *continue*. With condition (11), neither B nor A have an incentive to stop the standardization process. The proof is relegated to the appendix.

LEMMA 1. *Condition (11) implies* stop *by firm A to be strictly dominated.*

With this result in mind, we can concentrate on firm A's decision to either *continue* or *disclose*. As in the previous section, firm A, at every odd stage t has to decide whether to disclose right away and realize expected payoffs

$$\mathrm{E}_t\widehat{U}_A(disclose@t) = \mathrm{E}_t U_A(disclose@t) \tag{20}$$

in equation (12), or postpone disclosure by one round, meaning continue at t and disclose at $t+2$ with expected payoffs of

$$\begin{aligned} \mathrm{E}_t\widehat{U}_A(disclose@t+2) \quad = \quad & (1-\theta)\sum_{k=0}^{1} p^k \,(1-p)\,(1+\sigma(\alpha, t+k))\,h(t+k) + \\ & (1-\theta)\,p^2\,(1+\sigma(\alpha, t+2))\,H(t+2|q). \end{aligned} \tag{21}$$

Comparing the expected payoffs form delaying disclosure for the cases of ex-ante disclosure in the previous section (equation (13)) and this section's ex-post disclosure (equation (21)), we see that if firm A does not lose her bargaining leverage by missing the window of opportunity to disclose, the costs of delaying disclosure by one round are lower. In the ex-ante disclosure case, these costs result from (i) a lower success probability, $p < q$, and (ii) losing bargaining leverage, $\sigma = 0$, if either party fails to find a new component in $t+1$ or $t+2$. In equation (21) firm A does not lose her bargaining leverage, thus only the first cost factor applies.

Allowing for ex-post disclosure without depriving firm A of her bargaining leverage increases firm A's benefits from delaying disclosure and affects the results in Propositions 4 and 5. Proposition 7 summarizes—the proof is relegated to the appendix.

PROPOSITION 7. *Let $\alpha > 0$ and $q > 0$. In the case of ex-post disclosure, if the pre-disclosure success probability p is not too low, i.e., for $\hat{p} \leq p < q$ with $\hat{p} > 0$, disclosure of the patent is delayed, and the disclosure stage is $\hat{\tau} > 1$. Moreover, not sanctioning non-disclosure of intellectual property by enforcing it results in stronger incentives to delay disclosure. Also, if $p \in [\hat{p}, \bar{p})$, the patent is disclosed at stage $t = 1$ under ex-ante disclosure yet delayed under ex-post disclosure.*

The results in Proposition 7 together with the discussion above show that allowing for ex-post disclosure results in firm A's weaker incentives to disclose early in the standardization process. This has two main policy implications: The first is for standardization consortia and regards the choice of the disclosure rule. The SSOs that wish to limit the scope for opportunistic patent disclosure should specify that the declaration of relevant IPRs must happen before the end of the standardization process. However, this prescription needs to be enforced, and here comes the second implication, for antitrust agencies: Punishing the deceptive conduct of a patent holder that fails to comply with an early-disclosure rule is a necessary condition to limit patent ambush.

6 Parameterized Example

For a parameterized version of the model, suppose that $h(t) = 1 - \beta^t$ and

$$\sigma(\alpha, t) = \left(1 - \gamma^{t-1}\right) \alpha. \tag{22}$$

For the calibration of the model we use the parameter values in Table 1. Note that the condition in equation (11) is satisfied as long as $p \geq \frac{\theta}{\beta} = \frac{5}{16}$ (Stein, 2008).

Table 1: Calibration

Calibration						Cutoffs		Disclose	
α	β	γ	θ	q	p	$\bar{p}$	$\hat{p}$	τ	$\hat{\tau}$
$3/4$	$4/5$	$3/4$	$1/4$	$4/5$	$3/4$	0.652	0.635	3	21

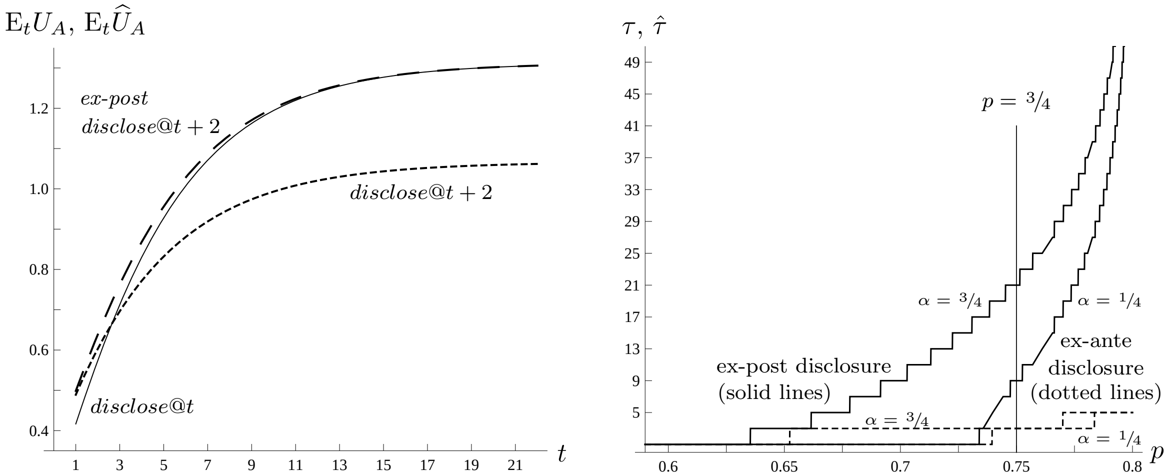
The table provides the critical values $\bar{p}$ and $\hat{p}$, where $\bar{p} > \hat{p}$ as derived in Proposition 7, for the lower bound of the pre-disclosure success probability that yields a delay of disclosure. Given $p = 3/4$, firm A will disclose in $t = \tau = 3$ in the baseline scenario with the imposed IP waiver, and in $t = \hat{\tau} = 21$ in the extension with ex-post disclosure.

[FIGURE 4 ABOUT HERE]

In Panel (a) of Figure 4 we plot as funtion of t the expected payoffs $\mathrm{E}_t U_A(disclose@t)$ disclosure at t (equation (12); solid line) and $\mathrm{E}_t U_A(disclose@t{+}2)$ for delayed disclosure at $t + 2$ (equation (13); dotted line) for the baseline model, and $\mathrm{E}_t \widehat{U}_A(disclose@t + 2)$ for delayed disclosure at $t + 2$ for the extension with ex-post disclosure (equation (21); dashed line).

For the given parameterization, firm A will delay disclosure by at least one round as the expected payoffs from disclsing at $t = 1$ (solid line) are strictly smaller than the payoffs from waiting another round (dashed and dotted lines). This is true for both the baseline model with the IP waiver and the extension with ex-post disclosure.

Figure 4: Disclosure: Parametric Example



Panel (a): Expected payoffs **Panel (b): Expected disclosure stage**

In Panel (b) of Figure 4 we plot as function of pre-disclosure success probability p the time of ex-ante disclosure τ with the IP waiver (dotted lines) and ex-post disclosure $\hat{\tau}$ (solid lines). We see a weak effect of p on the disclosure timing in the baseline case (see Proposition 5). For the extension with ex-post disclosure this effect is much more pronounced. We can also see that with higher α firms disclose later, given p.

7 Concluding Remarks

We have presented a model of communication with asymmetric information, based on the work by Stein (2008), with which we endogenize the magnitude of patent holdup to study the effect on the timing of patent disclosure of patent strength, the productivity of industry standard setting, and a standard setting organization's IPR disclosure rules. We find that late disclosure is more likely in more productive standard setting organizations and in less competitive industries. The intuition for the former result is that delaying patent disclosure increases the patent holder's bargaining leverage, which in turn results in higher license fees the more valuable the standard is. The latter result arises from the observation that rent extraction via opportunistic licensing is the more profitable the higher are the firms' market profits. Moreover, we find that enforcing antitrust laws against deceptive conduct in standard setting organizations, i.e., enforcing a standard setting organization's IPR disclosure rules, results in earlier disclosure. Recent litigation and the ongoing debate on the role of antitrust in standard setting[25] underscore the relevance of our results for the evaluation of legal and organizational policy.

[25] See chapter 2 in U.S. Dep't of Justice & Fed. Trade Comm'n (2007).

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A Appendix

Proof of Proposition 1

Proof. We assume a cooperative equilibrium with disclosure at $t = 1$ exists, implying that communication of ideas for components at all stages. We show that for sufficiently high θ the joint payoffs from continuing communication are smaller than from not continuing, i.e.,

$$\mathrm{E}U^C(continue@t) < U^C(stop@t) \tag{A.1}$$

for some t. As the expected joint payoffs are higher when the probability of success is $q > p$, it is straightforward to assume that A has disclosed that patent at $t = 1$. It suffices to show that there are values of θ such that the condition in (A.1) holds for some t. The joint payoffs from continuing are

$$\mathrm{E}U^C(continue@t) = 2\,(1-\theta)\sum_{i=0}^{\infty} q^i\,(1-q)\,h(t+i),$$

the joint payoffs from stopping are

$$U^C(stop@t) = h(t) + (1-2\theta)\,h(t-1).$$

By $h(t) > h(t-1)$, $U^C(stop@t) > 0$ for all θ; $\mathrm{E}U^C(continue@t) = 0$ for $\theta = 1$ and strictly positive otherwise. The critical value $\theta^C(q, h(\cdot))$ for which $\mathrm{E}U^C(continue@t) = U^C(stop@t)$ is strictly smaller than unity so that there are some $\theta > \theta^C(q, h(\cdot))$ for which (A.1) holds. Note, also, that this critical value is strictly larger than 0.5. Suppose for a moment that

$$\mathrm{E}\tilde{U}^C(continue@t) = 2\,(1-\theta)\sum_{i=0}^{\infty} q^i\,(1-q)\,h(t) = 2\,(1-\theta)\,h(t).$$

$\mathrm{E}\tilde{U}^C(continue@t) = U^C(stop@t)$ for $\theta = 0.5$, and the condition in equation (A.1) holds for $\theta > 0.5$. Because $h(t) < h(t+i)$ for all $i > 0$, $\mathrm{E}U^C(continue@t) > \mathrm{E}\tilde{U}^C(continue@t)$ and get $\theta^C(q, h(\cdot)) > 0.5$. Q.E.D.

Proof of Proposition 2

Proof. For the sake of this proof, we assume that $t \in (0,1) \subset \mathbb{R}_+$, so that t draws on real numbers bigger than unity. This simplifies the analysis without loss of generality. Moreover, for notational simplicity, let $\mathrm{E}_t(@t) := \mathrm{E}_t U_A(disclose@t)$ and $\mathrm{E}_t(@t{+}2) := \mathrm{E}_t U_A(disclose@t{+}2)$. Consider the following properties of the expected payoff functions $\mathrm{E}_t(@t)$ in equation (12) and $\mathrm{E}_t(@t+2)$ in equation (13).

- **P1**. $\mathrm{E}_t(@t)$ and $\mathrm{E}_t(@t+2)$ are strictly increasing in t because $\sigma(\alpha, t)$ (for $\alpha > 0$), $h(t)$, $h(t+1)$, and $H(t|q)$ are strictly increasing in t.

P2. Because $\lim_{t\to\infty} h(t+k) = 1$ for all $k \geq 0$ and $\lim_{t\to\infty} \sigma(\alpha, t) = \alpha$, we get

$$\lim_{t\to\infty} \mathrm{E}_t(@t) = (1-\theta)(1+\alpha), \tag{A.2}$$
$$\lim_{t\to\infty} \mathrm{E}_t(@t+2) = (1-\theta)\left(1+p^2\alpha\right), \tag{A.3}$$

P3. The value of $\mathrm{E}_t(@t)$ lies in a bounded space,

$$\mathrm{E}_t(@t) \in [\mathrm{E}_1(@1), \mathrm{E}_\infty(@\infty))$$

with $\mathrm{E}_1(@1) = (1-\theta)\, H(1|q) > 0$.

LEMMA A.1. *In the limit, the expected payoffs from delaying disclosure one round are* strictly *smaller than the payoffs from disclosing right away,* $\lim_{t\to\infty} \mathrm{E}_t(@t) > \lim_{t\to\infty} \mathrm{E}_t(@t+2)$.

Proof. By **P3** and $p < q \leq 1$. Q.E.D.

LEMMA A.2. *If* $\mathrm{E}_1(@1) < \mathrm{E}_1(@3)$*, then there exists a finite value* $\tilde{t} > 1$ *such that* $\mathrm{E}_t(@t+2) \leq \mathrm{E}_t(@t)$ *for all* $t \geq \tilde{t}$ *and* $\mathrm{E}_t(@t+2) > \mathrm{E}_t(@t)$ *for all* $t < \tilde{t}$.

Proof. By **P3** and the intermediate value theorem. Q.E.D.

LEMMA A.3. *The assumption that* $\mathrm{E}_t(@t)$ *and* $\mathrm{E}_t(@t+2)$ *intersect at most once implies that if condition (15) does not hold and* $\mathrm{E}_1(@1) > \mathrm{E}_1(@3)$ *then* $\mathrm{E}_t(@t) \geq \mathrm{E}_t(@t+2)$ *for all* $t \geq 1$.

Proof. By Lemma A.1. This situation is depicted in panel *(b)* of Figure 3. Q.E.D.

The proof for claim 2 of the proposition follows straight from Lemma A.3, which states that in t an expected-profit maximizing firm A prefers disclosing in t to waiting one round and disclosing in $t+2$. This result holds for all t, hence, firm A in $t+2$ prefers disclosing in $t+2$ to waiting one round and disclosing in $t+4$. Anticipating her stage-$t+2$ decision in t, the firm in t prefers disclosing in t to waiting two rounds and disclosing in $t+4$; and so forth. By this argument, firm A will disclose the patent in $t = 1$.

P4. Expected payoffs $\mathrm{E}_t(@t+2)$ can be rewritten as an increasing function of $\mathrm{E}_t(@t)$:

$$\mathrm{E}_t(@t+2) := p^2 \rho(\mathrm{E}_t(@t)) \tag{A.4}$$

with

$$\rho(\mathrm{E}_t(@t) := \mathrm{E}_t(@t) + (1-\theta)\left(\phi + \frac{\sum_{k=0}^{1} p^k (1-p)\, h(t+k)}{p^2}\right) \tag{A.5}$$

where

$$\phi = (1+\sigma(\alpha, t+2))\, H(t+2|q) - (1+\sigma(\alpha, t))\, H(t|q)$$

and

$$\mathrm{E}_{t+2}(@t+2) = \mathrm{E}_t(@t) + (1-\theta)\, \phi = (1-\theta)\, (1+\sigma(\alpha, t+2))\, H(t+2|q).$$

With property **P4** we can formulate firm A's present value maximization problem in a recursive fashion. For further notational simplicity, let $D := \mathrm{E}_t(@t)$ and $\rho(D) := \rho(\mathrm{E}_t(@t)) = \mathrm{E}_t(@t+2)/p^2$. Consequently, the problem of firm A can be rewritten as

$$\mathcal{P}: \quad V(D) = \max\left\{D, p^2 V[\rho(D)]\right\}. \tag{A.6}$$

Moreover, let $\underline{D} = \mathrm{E}_1(@1)$, $\tilde{D} = \mathrm{E}_t(@\tilde{t})$, and $\rho(\tilde{D}) = \mathrm{E}_t(@\tilde{t}+2)/p^2$ with $\tilde{t}$ defined in Lemma A.2. In $\mathcal{P}$, D is the state variable and the objective is to determine the timing of disclosure. Three of the necessary conditions, guaranteeing that a fixed point that solves $\mathcal{P}$ exists and is unique (Stokey and Lucas, 1989), hold true:

NC1. D takes values in a bounded set [by **P3**]

NC2. $\rho(D)$ is increasing in D [by **P4**]

NC3. $\exists \tilde{D} : \rho(\tilde{D}) = \tilde{D}/p^2$ [by Lemma A.2]

These three conditions are necessary to establish the existence of a functional fixed point to the stopping problem we are analyzing. Yet, the additional condition that has to be discussed regards the initial condition, that is, the condition on the value of the payoffs associated with disclosure right away instead of waiting until $t = 3$. Two cases must be distinguished, depending on whether the initial condition prescribes immediate disclosure or not.

Case (i) If $\rho(\underline{D}) < \underline{D}/p^2$, then, by Lemma A.3 the initial condition prescribes that disclosure should take place right away.

In the following we study case (ii), in which at $t = 1$ the agent finds it profitable to delay disclosure. The objective of the analysis that follows is to show that a function (or simple rule) that prescribes to disclose at some $\tau \geq \tilde{t} > 1$ exists and is unique. Note that because the disclosure stage τ is restricted to odd integers, but $\tilde{t}$ can be any real number larger than unity, τ is defined as

$$\tau = \begin{cases} \lceil \tilde{t} \rceil & \text{if } \lceil \tilde{t} \rceil \text{ is an odd integer} \\ \lceil \tilde{t} \rceil + 1 & \text{if otherwise} \end{cases} \tag{A.7}$$

For **Case (ii)** we assume $\rho(\underline{D}) \geq \underline{D}$ (i.e., equation (15) holds) and $\mathrm{E}_t(@t)$ and $\mathrm{E}_t(@t+2)$ intersect at most once. Referring to **NC3**, this is the case if

$$\forall D > \tilde{D} : p^2\rho(D) < D \quad \text{and} \quad \forall D < \tilde{D} : p^2\rho(D) > D.$$

The contraction mapping theorem can be applied and a simple stopping rule exists. To show this, we first prove that Blackwell's monotonicity and discounting conditions are satisfied (Blackwell, 1965). An operator T is a contraction mapping if the following two conditions hold:[26]

[26]In the following we use $f(\cdot)$ and $g(\cdot)$ to denote the candidate solution to our functional fixed point problem.

Monotonicity: $\forall x$**,** $f(x) \le g(x)$ **then** $Tf(x) \le Tg(x)$ **for all** x**.**

Monotonicity is satisfied because, if $\forall x \ f(x) \le g(x)$, then $p^2 f(\rho(D)) \le p^2 g(\rho(D))$ and $\max\left\{D, p^2[f(\rho(D))]\right\} \le \max\left\{D, p^2[g(\rho(D))]\right\}$. Monotonicity implies that if $f(x) \le g(x)$ then the objective function for which $\max\left\{D, p^2[g(\rho(D))]\right\}$ is the maximized value is uniformly higher than the function for which $\max\left\{D, p^2[f(\rho(D))]\right\}$ is the maximized value.

Discounting: For a scalar a **define** $(f+a)(x) = f(x)+a$**.** $\exists \beta \in (0,1)$**,** $T(f+a)(x) \le Tf(x) + \beta a$**, for all** $f, a \ge 0$ **and** x **in the state space.**

Discounting is satisfied because the following holds:

$$\begin{aligned} \max\left\{D, p^2[f(\rho(D)) + a]\right\} &\le \max\left\{D + p^2 a, p^2[f(\rho(D)) + a]\right\} \\ &= \max\{D, p^2[f(\rho(D))]\} + p^2 a. \end{aligned}$$

Consequently, the functional problem $\mathcal{P}$ has a unique fixed point $V(\cdot)$. In other words, we can identify a unique function that solves the maximization problem in $\mathcal{P}$ for each value of the state variable; such a function provides a rule that prescribes the optimal decision (disclose/delay) depending on the value of the state variable D. More specifically, the functional fixed point $V(\cdot)$ is increasing, meaning that if $f(D') \le f(D'') \ \forall D' \le D''$, then $p^2 f(D') \le p^2 f(D'')$ and $\max\left\{D, p^2 f(\rho(D'))\right\} \le \max\left\{D, p^2 f(\rho(D''))\right\}$.

To conclude the proof, we determine the optimal simple disclosure rule by following the next two steps, where, as above, $f(\cdot)$ denotes a candidate fixed point solution.

1. Assume $\forall D > \tilde{D} : f(D) \le D$. Then

   $$\max\{D, p^2 f(\rho(D))\} \le \max\{D, p^2 f(D/p^2)\} = p^2 \max\{D/p^2, f(D/p^2)\} = D,$$

   meaning that once we start with a function f that satisfies the assumption all the future iterations stick to it and the same happens to the fixed point. This implies that $\forall D > \tilde{D} : V(D) = D$. Hence, A should disclose for all $D > \tilde{D}$.

2. Assume $\forall D < \tilde{D} : f(D) > D$. Then

   $$\begin{aligned} \max\{D, p^2 f(\rho(D))\} \ge \max\{D, p^2 f(D/p^2)\} &= p^2 \max\{D/p^2, f(D/p^2)\} \\ &= p^2 f(D/p^2) > p^2 D/p^2 = D. \end{aligned}$$

   Also in this case, once we start with a function f that satisfies the assumption the future iterations and the fixed point stick to it. This implies that $\forall D < \tilde{D} : V(D) > D$, that is, A should not disclose for all $D < \tilde{D}$.

Therefore, the optimal rule prescribes disclosure if and only if

$$\forall D \ge \tilde{D} : \rho(\tilde{D}) = \tilde{D}/p^2.$$

Strictly speaking, such a rule suggests to disclose at the lowest $t \ge \tilde{t}$, where $\tilde{t}$ is defined in Lemma A.2 and t an odd integer. Q.E.D.

Proof of Proposition 3

Proof. By Proposition 2, and the regularity condition therein, the necessary and sufficient condition for player A to delay patent disclosure at $t = 1$, so that $\tau > 1$, is

$$\mathrm{E}_1 U_A(disclose@1) \leq \mathrm{E}_1 U_A(disclose@3).$$

After some manipulation, we can rewrite this as

$$\sum_{k=0}^{1} \left[q^k (1-q) - p^k (1-p)\right] h(1+k) \leq \left[(1+\sigma(\alpha,3)) p^2 - q^2\right] \sum_{k=0}^{\infty} q^k (1-q) h(3+k).$$

For the proof of the proposition, we show that, given $q > p$, the necessary and sufficient condition for delayed disclosure is not satisfied. This means, for $\alpha = 0$ so that $\sigma(\alpha, 3) = 0$, we show that

$$\left[q^2 - p^2\right] \sum_{k=0}^{\infty} q^k (1-q) h(3+k) + \sum_{k=0}^{1} \left[q^k (1-q) - p^k (1-p)\right] h(1+k) > 0.$$

This expression can be rearranged to read

$$\sum_{k=0}^{\infty} q^k (1-q) h(1+k) - \sum_{k=0}^{1} p^k (1-p) h(1+k) - p^2 \sum_{k=0}^{\infty} q^k (1-q) h(3+k) > 0$$

and, by the definition of $H(t|q)$ in equation (6) for $t = 1$ and $t = 3$,

$$H(1|q) - \sum_{k=0}^{1} p^k (1-p) h(1+k) - p^2 H(3|q) > 0. \tag{A.8}$$

To show that this last inequality holds for all $q > p$, first note that

$$H(1|q) = \sum_{k=0}^{1} q^k (1-q) h(1+k) + q^2 H(3|q).$$

If

$$\sum_{k=0}^{1} q^k (1-q) h(1+k) + q^2 H(3|q) > \sum_{k=0}^{1} p^k (1-p) h(1+k) + p^2 H(3|q) \tag{A.9}$$

then (A.8) holds with strict equality and condition (15) in Proposition 2 is violated for $\alpha = 0$. We can rewrite (A.9) as

$$h(1) + q\left[h(2) - h(1)\right] + q^2\left[H(3|q) - h(2)\right] > h(1) + p\left[h(2) - h(1)\right] + p^2\left[H(3|q) - h(2)\right].$$

It holds if

$$H(3|q) - h(2) > 0. \tag{A.10}$$

Because $H(3|q) = (1-q)\, h(3) + \sum_{k=1}^{\infty} q^k\, (1-q)\, h(3+k)$, (A.10) holds true if and only if

$$h(3) - h(2) + \sum_{k=1}^{\infty} q^k\, (1-q)\, h(3+k) - qh(3).$$

We can further expand the summation to get

$$h(3) - h(2) + q\, [h(4) - h(3)] + \sum_{k=2}^{\infty} q^k\, (1-q)\, h(3+k) - q^2 h(4)$$

and

$$q^0\, [h(3) - h(2)] + q^1\, [h(4) - h(3)] + q^2\, [h(5) - h(4)] + \sum_{k=3}^{\infty} q^k\, (1-q)\, h(3+k) - q^3 h(5).$$

As we continue the expansion, the last term, $q^i h(2+i)$ is equal to zero in the limit, since $i \to \infty$. All other terms, $q^i\, [h(3+i) - h(2+i)]$ are strictly positive so that (A.10) holds true. Q.E.D.

Proof of Proposition 4

Proof. We prove the claim by applying the intermediate value theorem. First, note that $\mathrm{E}_t U_A(disclose@1) - \mathrm{E}_t U_A(disclose@3)$, or

$$(1-\theta)\left\{ \sum_{k=0}^{1} \Big[q^k\, (1-q) - p^k\, (1-p) \Big]\, h(1+k) - \left[(1 + \sigma(\alpha, 3))\, p^2 - q^2 \right] H(3|q) \right\}, \qquad \text{(A.11)}$$

is strictly positive for $q > 0$ and $p = 0$. The expression in (A.11) can be rewritten[27] as

$$(1-\theta)[H(1|q) - h(1)] > 0.$$

This inequality holds by equation (7) for $t = 1$ and because $\theta > 0$ and $h(0) = 0$. Note that equation (7) holds by equation (11), which is the underlying assumption of this section's analysis.

If, instead, $p = q$, then (A.11) is reduced to

$$-q^2 \sigma(\alpha, 3) H(3, q)(1-\theta) < 0.$$

For a given q, (A.11) is continuous in p and strictly decreasing in p with the first derivative

[27] Note, that $\lim_{p \to 0} p^0 = 1$.

with respect to p,

$$
\begin{aligned}
-(1-\theta)\left\{\sum_{k=0}^{1}\left[kp^{k-1}(1-p)-p^{k}\right]h(1+k)+2p\,(1+\sigma(\alpha,3))\,H(3|q)\right\} &= \\
-(1-\theta)\left\{[-h(1)+(1-2p)\,h(2)]+2p\,(1+\sigma(\alpha,3))\,H(3|q)\right\} &= \\
-(1-\theta)\left\{\left[h(2)-h(1)+2p\sum_{k=0}^{\infty}q^{k}\left[h(3+k)-h(2+k)\right]\right]+2p\sigma(\alpha,3)H(3|q)\right\} &< 0.
\end{aligned}
$$

To summarize, $\mathrm{E}_t U_A(disclose@1)-\mathrm{E}_t U_A(disclose@3)$ is strictly positive (firm A discloses at $t=1$) for $p=0$ and strictly negative (firm A delays disclosure) for $p=q$; moreover, it is continuous and strictly decreasing in p. Hence, by the intermediate value theorem, there exists a value $\bar{p} := \bar{p}(q,\sigma(\cdot),h(\cdot))$ with $\bar{p}\in(0,q)$ for the pre-disclosure probability p such that $\mathrm{E}_t U_A(disclose@1) > \mathrm{E}_t U_A(disclose@3)$ and disclosure at $t=1$ for all $p<\bar{p}$; and $\mathrm{E}_t U_A(disclose@1) \leq \mathrm{E}_t U_A(disclose@3)$ and disclosure at a later stage for all $p \geq \bar{p}$. Q.E.D.

Proof of Proposition 5

Proof. By Lemma A.2, $\tilde{t}$ is such that

$$F := \mathrm{E}_{\tilde{t}} U_A(disclose@\tilde{t}) - \mathrm{E}_{\tilde{t}} U_A(disclose@\tilde{t}+2) = 0.$$

We can define τ as

$$\tau = \begin{cases} \lceil \tilde{t} \rceil & \text{if } \lceil \tilde{t} \rceil \text{ is an odd integer} \\ \lceil \tilde{t} \rceil + 1 & \text{if otherwise} \end{cases} \tag{A.12}$$

By this definition, an increase in $\tilde{t}$ is a measure for firm A's *propensity* to delay disclosure.

By the implicit function theorem,

$$\frac{d\tilde{t}}{dp} = -\left.\frac{\partial F}{\partial p}\right/\frac{\partial F}{\partial \tilde{t}}$$

and

$$\frac{d\tilde{t}}{d\alpha} = -\left.\frac{\partial F}{\partial \alpha}\right/\frac{\partial F}{\partial \tilde{t}}\ .$$

By Lemma A.2, $F>0$ for $t>\tilde{t}$ and $F<0$ for $t<\tilde{t}$. Hence, F is increasing in t at $\tilde{t}$; $\frac{\partial F}{\partial \tilde{t}}>0$. Moreover,

$$\frac{\partial F}{\partial p} = -(1-\theta)\sum_{i=0}^{\infty} q^{i}\left[h(\tilde{t}+2+i)-h(\tilde{t}+1+i)\right] < 0.$$

Hence,

$$\frac{d\tilde{t}}{dp} = -\left.\frac{\partial F}{\partial p}\right/\frac{\partial F}{\partial \tilde{t}} > 0$$

and $\tilde{t}$, as a measure for the propensity to delay disclosure, is increasing in the pre-disclosure success probability p.

For the effect of α on $\tilde{t}$, we find that

$$\frac{\partial F}{\partial \alpha} = (1-\theta)\left[\frac{\partial \sigma(\alpha,\tilde{t})}{\partial \alpha} H(\tilde{t}|q) - p^2 \frac{\partial \sigma(\alpha,\tilde{t}+2)}{\partial \alpha} H(\tilde{t}+2|q)\right].$$

This expression is negative, and $d\tilde{t}/d\alpha > 0$, if and only if condition (16) holds true. Q.E.D.

Proof of Proposition 6

Proof. We begin the proof by showing that if condition (11) does not hold for *all* t, then player B will *stop* at $t = 2$. Put differently, if (11) holds for all $t < \hat{t}$, but is violated for $t \geq \hat{t}$, communication does not continue until $t = \hat{t} - 1$. This is by a simple backward-induction argument. Let $\hat{t}$ be even so that player B is the one to stop (the following argument applies also to an odd $\hat{t}$). At $\hat{t} - 1$, player A will either *stop* or *continue*. If she stops, her payoffs are $U_A(stop@\hat{t}-1) = (1-\theta)\,h(\hat{t}-1) + \theta[h(\hat{t}-1) - h(\hat{t}-2)]$. If she continues, with probability p she expects player B to have another idea but *stop* the process. Her respective payoffs are $(1-\theta)\,h(\hat{t}-1)$. With probability $1-p$, she expects player B to fail; her respective payoffs are $(1-\theta)\,h(\hat{t}-1)$. Then, her payoffs from *continue* are equal to $\mathrm{E}_{\hat{t}-1}U_A(continue@\hat{t}-1) = (1-\theta)\,h(\hat{t}-1)$. Because $h(\hat{t}-1) > h(\hat{t}-2)$, $U_A(stop@\hat{t}-1) > \mathrm{E}_{\hat{t}-1}U_A(continue@\hat{t}-1)$.

Anticipating that player B stops at $\hat{t}$ induces player A to stop at $\hat{t}-1$. At $\hat{t}-2$, player B decides whether to *continue* or *stop*. By the very same argument, anticipating that player A stops at $\hat{t}-1$ induces player B to stop at $\hat{t}-2$. The process unravels, and player B stops at $t = 2$ if condition (11) is violated for some t.

Because $\mathrm{E}_1U_A(continue@1) < U_A(stop@1)$ (given that condition (11) does not hold), player A will not continue at $t = 1$ absent disclosure. But she may decide to disclose the patent at $t = 1$. Indeed, disclosure can only happen at $t = 1$; because if A continues without disclosing at $t = 1$ the game ends at $t = 2$. Moreover, given that disclosure takes place at $t = 1$, $\sigma(\alpha, 1) = 0$.

We can now provide the proof of the proposition: If after disclosure a communication equilibrium cannot be sustained (that is, if (7) does not hold for all t), then player A will not disclose. Instead, if (7) holds, then player A discloses at $t = 1$.

1. First, note that if (7) does not hold for all t, then player B will stop at $t = 2$. This is by the argument provided above for pre-disclosure communication. Player A's payoffs if she stops are $U_A(stop@1) = (1-\theta)\,h(1) + \theta[h(1) - h(0)] = h(1)$. Her payoffs for disclosure are $\mathrm{E}_1U_A(disclose@1) = (1-\theta)\,h(1)$. For all $\theta > 0$, $U_A(stop@1) > \mathrm{E}_1U_A(disclose@1)$ and player A stops.

2. Second, condition (7) implies condition (10); after disclosure a communication equilibrium can be sustained. Player A's payoffs for disclosure are

$$\mathrm{E}_1U_A(disclose@1) = \mathrm{E}_1U_A(continue@1|1) = (1-\theta)\,H(1|q).$$

She will disclose if $(1-\theta)\, H(1|q) \geq h(1) = U_A(stop@1)$ or, for $h(0) = 0$,

$$\frac{H(1|q)}{h(1)} = \frac{H(1|q) - h(0)}{h(1) - h(0)} \geq \frac{1}{1-\theta}.$$

If (7) holds for all t, then it holds for $t = 1$, and the above condition holds. This concludes the proof. Q.E.D.

Proof of Lemma 1

Proof. *Stop* is dominated by *continue* if $\mathrm{E}_t \widehat{U}_A(continue@t) \geq \widehat{U}_A(stop@t)$ if and only if

$$\frac{\widehat{H}(t|p) - (1 + \sigma(\alpha, t))\, h(t-1)}{h(t) - h(t-1)} \geq \frac{1}{1-\theta}. \tag{A.13}$$

We assume condition (11) holds; and (11) implies (A.13) if and only if

$$\widehat{H}(t|p) - (1 + \sigma(\alpha, t))\, h(t-1) \geq H(t|p) - h(t-1)$$

or

$$\sum_{i=0}^{\infty} p^i\, (1-p)\, h(t+i) \sigma(\alpha, t+i) \geq \sigma(\alpha, t) h(t-1). \tag{A.14}$$

Because

$$\sum_{i=0}^{\infty} p^i\, (1-p)\, h(t+i) = h(t) + \sum_{i=0}^{\infty} p^i\, (1-p)\, [h(t+i) - h(t)] > h(t-1)$$

and $\sigma(\alpha, t+i)$ an increasing weight on the LHS, (A.14) holds with strict equality. Q.E.D.

Proof of Proposition 7

Proof. We want to show that there exists a cutoff value $\hat{p}$ for pre-sucess probability p such that (i) greater values of p trigger disclosure delay at $t = 1$ and (ii) such a cutoff value is lower than in the case with ex-ante disclosure ($\bar{p}$).

We apply the intermediate value theorem. First, note that

$$\mathrm{E}_1 \widehat{U}_A(disclose@1) - \mathrm{E}_1 \widehat{U}_A(disclose@3),$$

or

$$(1-\theta) \left[H(1|q) - \sum_{k=0}^{1} p^k\, (1-p)\, h(1+k)(1 + \sigma(\alpha, 1+k)) - p^2 (1 + \sigma(\alpha, 3) H(3|q) \right], \tag{A.15}$$

is strictly positive for $q > 0$ and $p = 0$. The expression in (A.15) can be rewritten[28] as

$$(1-\theta)[H(1|q) - h(1)] > 0.$$

[28] Note, that $\lim_{p \to 0} p^0 = 1$.

This inequality holds by equation (7) for $t = 1$ and because $\theta > 0$ and $h(0) = 0$. Note that equation (7) holds by equation (11), which is the underlying assumption of this section's analysis.

If, instead, $p = q$, then (A.15) is reduced to

$$-(1-\theta)\left[q^2\sigma(\alpha,3)H(3,q) + \sum_{k=0}^{1} q^k (1-q)\, h(1+k)(1+\sigma(\alpha,1+k))\right] \quad < \quad -(1-\theta)[q^2\sigma(\alpha,3)H(3,q) \quad < \quad 0.$$

For a given q, (A.15) is continuous in p and strictly decreasing in p with the first derivative with respect to p equal to

$$-(1-\theta)\left\{\sum_{k=0}^{1}\left[kp^{k-1}(1-p) - p^k\right](1+\sigma(\alpha,1+k))h(1+k) + 2p\,(1+\sigma(\alpha,3))\,H(3|q)\right\} \quad =$$

$$-(1-\theta)\left\{[-h(1) + (1-2p)\,h(2)(1+\sigma(\alpha,2))] + 2p\,(1+\sigma(\alpha,3))\,H(3|q)\right\} \quad =$$

$$-(1-\theta)\left\{(1+\sigma(\alpha,2))h(2) - h(1) + 2p\sum_{k=0}^{\infty} q^k\,[h(3+k)(1+\sigma(\alpha,3+k)) - h(2+k)(1+\sigma(\alpha,2+k))]\right\} \quad < \quad 0.$$

To summarize, $\mathrm{E}_1\widehat{U}_A(disclose@1) - \mathrm{E}_1\widehat{U}_A(disclose@3)$ is strictly positive (firm A discloses at $t = 1$) for $p = 0$ and strictly negative (firm A delays disclosure) for $p = q$; moreover, it is continuous and strictly decreasing in p. Hence, by the intermediate value theorem, there exists a value $\hat{p} := \hat{p}(q, \sigma(\cdot), h(\cdot))$ with $\hat{p} \in (0, q)$ for the pre-disclosure probability p such that $\mathrm{E}_1\widehat{U}_A(disclose@1) > \mathrm{E}_1\widehat{U}_A(disclose@3)$ and disclosure at $\hat{\tau} = 1$ for all $p < \hat{p}$; and $\mathrm{E}_1\widehat{U}_A(disclose@1) \leq \mathrm{E}_1\widehat{U}_A(disclose@3)$ and disclosure at a later stage for all $p \geq \hat{p}$.

Finally, since for $p = 0$, the expressions in (A.11) and (A.15) take the same value and for $p = q$ (A.15) is lower than (A.11), $\hat{p}$ is smaller than $\bar{p}$ (the cutoff value defined in the proof of Proposition 4). This implies that for $p \in [\hat{p}, \bar{p})$ firm A delays disclosure under ex-post disclosure while it discloseses her patent under ex-ante disclosure at stage $t = 1$. Q.E.D.