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Patent Disclosure in Standard Setting*

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Abstract

We present a model of industry standard setting with two-sided asymmetric information about the existence of intellectual property. We provide an equilibrium analysis of (a) firms' incentives to communicate ideas for improvements of an industry standard, and (b) firms' decisions to disclose the existence of intellctual property to other participants of the standardization process.

JEL classification: D71, L15, O34

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

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1 Introduction

Industry 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] In this paper, we study how the effectiveness of the standardization process is affected when new technologies included in standards are patent-protected. We investigate to what extent the scope for "opportunistic" disclosure of these patents undermines the work of a standard setting organization (SSO), a forum for reaching consensus under competitive and strategic tensions.

Conflicting and vested interests, that may arise from problems of asymmetric information or tensions due to fierce product market competition, can have a significant impact on the process. Simcoe (2008) and Farrell and Simcoe (2009) highlight the impact of strategic interests on the delay of standard adoption. These strategic effects are likely to be amplified if the standard incorporates intellectual property.[4] Feldman, Graham, and Simcoe (2009), for example, document that patents disclosed to SSOs are highly litigated.[5] In a related context, Chiao, Lerner, and Tirole (2007) analyze the relationship between intellectual property disclosure rules and the level of license prices. Such disclosure of intellectual property—especially when delayed—may be used strategically as it can provide the patent holder with a bargaining leverage

[1] See, e.g., the discussions of standards and network effects in Scotchmer (2004) or Shapiro and Varian (1998).

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

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

[4] See Weiss and Sirbu (1990:2026) or Farrell and Klemperer (2007).

[5] Moreover, Baron and Pohlmann (2010) study the effect of patent pools on patent disclosure and find that patent pools result in more patent disclosure, suggesting opportunistic patent filings.

over patent's prospective users—a phenomenon often referred to as patent holdup or patent ambush.[6]

In this paper, we endogenize the magnitude of patent holdup and study how patent strength, the efficiency of the standardization process, and product-market competition affect the strategic use of disclosure of intellectual property. We provide two results concerning firms' disclosure decisions. First, we find that in the presence of valid intellectual property, patent holders strategically delay the disclosure of intellectual property. Moreover, the propensity to delay disclosure is stronger in more productive standardization bodies. We also study the impact of product market competition on the development of the standardization process. In this respect, we find that harsh competition inhibits even the start of the standardization process. As competition gets softer, the standardization process is started, but the decision to disclose can be constrained by the risk that other firms leave the SSO before a patent holder's optimal disclosure timing has arrived. Finally, soft competition allows patent holders to fully exploit their bargaining leverage and postpone disclosure until the aspired stage.

We present a dynamic model with asymmetric information, based on Stein (2008), in which two product-market competitors are engaged in the process of standardization. They take turns in suggesting new ideas for standard improvements. We make two main assumptions: First, ideas for improvements are complementary insofar as a firm can find a new idea only if the other firm has suggested an idea in the previous round (e.g.,

[6]See Farrell, Hayes, Shapiro, and Sullivan (2007); Lemley and Shapiro (2007); Farrell and Shapiro (2008); Ganglmair, Froeb, and Werden (2010); Shapiro (2010); Tarantino (2011), among others. 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.

Stein, 2008; Hellmann and Perotti, 2010).[7] Second, the model's information structure is asymmetric. We assume that the initial standard technologies are patent-protected and respective patent holders must decide when to disclose this information to the other participants. Chiao, Lerner, and Tirole (2007:911) 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."[8] Therefore, unless disclosed by its holder, members of an SSO may at best have a prior belief as to whether or not a given (essential) technology in the standard is patent protected.[9]

The owner of intellectual property of such an essential part of the standard can demand the payment of license fees from other firms producing within the standard. These license fees depend on the patent holder's bargaining leverage as a result of the technology users' lock-in. Such lock-in arises from firms relying on the standard to be adopted and then manufacturing final products based on the present state of the not yet adopted standard proposal.[10] We assume that the extent of lock-in increases the later the patent holder discloses its intellectual property. The existing literature on the ensuing problem of patent holdup in standard setting[11] assumes the magnitude

[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.

[8]The identification of a patent that is relevant to the development of a specific standard imposes significant search costs on the firms participating in an SSO, especially when firms with very large patent portfolios are involved in the discussion. 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)

[9]Kobayashi and Wright (2009) or Shapiro (2010) assume naïve manufacturers who are not aware of the possibility of the technology being patent protected.

[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]Remarkably, many of the cases regarding SSOs deal with disclosure issues: In the

of holdup to be exogenous. In this paper we model the decision to disclose intellectual property (with exogenous patent strength (Farrell and Shapiro, 2008)) and thus endogenize the degree of lock-in and holdup, and consequently the size of license fees.

We analyze the patent holder's disclosure decision in two regimes, the *waiver* and the *no-waiver* regime. For the waiver regime we assume that if the patent holder fails to disclose its patent before the end of the standardization process, its intellectual property is treated as if waived.[12] This implies that the firm loses its bargaining leverage—and thus its license fee revenues—over users of the standard. In the no-waiver regime, patent holders can disclose before or after the end of the standardization process, without the implied waiver and the loss of their bargaining leverage. These two regimes naturally map into the two main disclosure rules employed by SSOs.[13]

Our model design gives rise to two tradeoffs to be analyzed. The first tradeoff is—though in a different context—analyzed in Stein (2008) and concerns firms' decisions to communicate respective ideas for standard improvement. A longer standardization process increases the quality of the standard, so firms share a common interest in continuing communication as long as possible. On the other hand, if a firm stops

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.

[12] 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.")*.

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

communication and does not reveal a new idea for improvement, it gains a cost advantage over its product-market rival. This latter effect introduces an incentive to halt communication during the standardization process.

The second tradeoff concerns firms' disclosure decision. In the waiver regime, by disclosing early, the patent holder loses part of its bargaining leverage from patent holdup. However, by delaying disclosure the patent holder runs the risk of not getting to disclose in time before the standardization process stops because no new idea for improvement arrives. Clearly, in the no-waiver regime there are no costs of not disclosing the patent, that is, there is no threat of losing one's bargaining leverage when missing the window of opportunity.

We derive our results by looking at two scenarios. First, we consider the case in which a patent holder's decision to disclose is not constrained by the other firm's incentives to communicate in the standardization process, meaning that the product market rival does not want to stop the standardization process. This allows us to analyze each patent holder's *aspired* disclosure stage and derive conditions for delayed disclosure. We then proceed to the case in which the disclosure decision is constrained in the following sense: the other firm's communication incentives may be binding and do not enable a given patent holder to continue the standardization process until the aspired disclosure stage. Explicitly accounting for the latter case, we are able to give conditions under which the unconstrained results cease to apply.

Our model suggests that a valid patent is a necessary condition for the patent holder to delay disclosure, i.e., not disclose at the beginning of the standardization process. We can further qualify this result to assess the impact of disclosure rules on the decision to postpone disclosure. In the no-waiver regime, firms disclose respective intellectual property only after the end of the standardization process. Instead, in the waiver regime , while delayed, firms plan to reveal the existence of intellectual property before the end of the process. In the waiver regime, we also find that the propensity to delay disclose is stronger in SSOs that exhibit a higher *productivity*, i.e., in which the probability with which firms have ideas for further standard improvement, is bigger. In this case, an increase in the productivity of the process implies a delay of disclosure. The strength of firm i's patent increases the incentives to delay firm i's patent disclosure if the relative gains from delaying offset the costs of time (that is, the risk that the process stops beforehand). The propensity to delay disclosure of firm i is independent of the strength of firm j's patent. This results from the combined effect of two features of the model. First, the (possible) existence of firm j's intellectual property equally affects the payoffs from disclosing right away and from delaying disclosure. Second, the decision to disclose by i has no spillover on the decision taken by j. Finally, market competition does not affect the aspired disclosure stage.

For a second set of results, we disentangle the effect of the degree of product market competition on the functioning of the standardization process and the timing of disclosure. We show that in a highly competitive industry cooperative standardization cannot be sustained. Intuitively, strong competitive pressures impair the agents' incentives to cooperate on the development of a standard. This is because 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.

To our knowledge our model is the first to endogenize patent holdup in standard setting. This means, given patent strength, bargaining leverage is contingent on when the patented technology is included in the standard: the later the patent is disclosed the more manufacturers are locked in and the greater is the threat of being held up in ex-post license negotiations. However, 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. He shows, by means of case studies, that cooperative communication between competitors can take place; such conversation, however, is not sustainable when very harsh competition is at work.[14] We deliver the analogous result that tough competition impedes firms' discussions and prevents cooperative standardization. With a focus 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 between competing agents. They assume that each agent can quit the information sharing game with its own solution to the problem, whereas we rule this out; a successful standardization 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 standardization process cannot be sustained if competition is too fierce. In Section 4 we analyze firms' incentives to continue communication after all patents have been disclosed. In Section 5 we analyze non-cooperative equilibrium disclosure when the firms' communication incentives are not binding. In Section 6 we explicitly model the case in which communication incentives may be binding and show

[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).

how they constrain patent holders' disclosure decision. We conclude in Section 7. The formal proofs of the results are relegated to the appendix.

2 Basic Model

We consider two product-market competitors, firm A and firm B, that take turns in creating or improving an existing technology as industry standard. They do this by exchanging ideas for improvement that arrive with exogenous probability. The process is characterized by strict complementarity of ideas, meaning that if a new idea does not arrive or one of the firms decides not to share a new idea with its competitor the process stops. Once stopped, the standard then comprises the stock of ideas exchanged. The larger the number of improvements, the more valuable the standard is to the firms. At the same time, by not sharing an idea, a firm gains an advantage over its competitor. Stein (2008) captures this tradeoff in his model of conversation among competitors. We follow the notation and extend his analysis by adding intellectual property and its disclosure to the model.

2.1 Information Structure

The firms take turns with A moving at stages $t = 1, 3, 5, \ldots$ and B moving at stages $t = 2, 4, 6, \ldots$. We denote the first stage at which a firm i gets to move by t_i^0 so that $t_A^0 = 1$, $t_B^0 = 2$, and $T_i := \{t_i^0, t_i^0 + 2, t_i^0 + 4, \ldots\}$. At stage $t = 1$, firm A has access to a patent-protected technology χ_1, and firm B has prior beliefs $\pi^B > 0$ this technology is being protected by a patent. If, at $t = 1$, firm A shares this technology with firm B, then B observes with probability $p \in (0, 1)$ a technology or idea χ_2 that improves firm A's technology and thus increases the value of the standard. Firm B happens to have a patent on this technology χ_2 with probability $\pi^A > 0$. This π^A is the prior probability and firm A's prior belief that χ_2 is patent protected. All future ideas χ_t, $t \geq 3$, are not patent-protected. Beliefs π^A and π^B are common knowledge.

Once a new idea has arrived, firm A at any odd $t \in T_A$ and firm B at any even $t \in T_B$ have three possible actions: (1) *stop* (not share χ_t), (2) *continue* (share χ_t but not the fact that $\chi_{t_i^0}$ is patent-protected), or (3) *disclose* (share χ_t and, if not done at an earlier stage, the fact that $\chi_{t_i^0}$ is patent-protected). Note that if firm i chooses to continue but not to disclose the patent at $t = t_i^0$, it can reconsider and disclose at any later t. A firm cannot credibly communicate that it does *not* have a patent on its technology. We restrict firms' precommitment as follows:

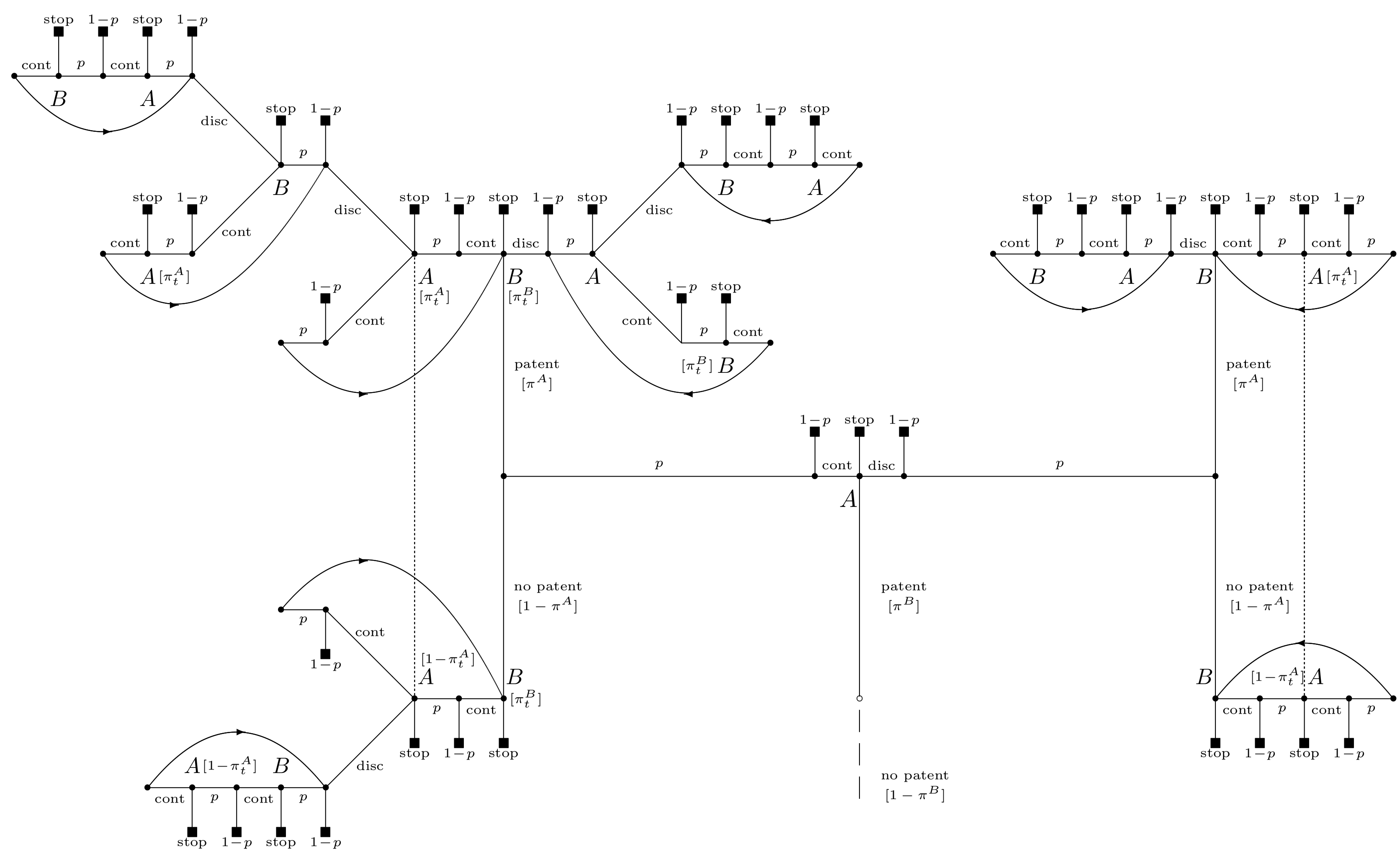
ASSUMPTION 1. *Firms cannot at any time t precommit to disclose at $t+k$, $k \geq 2$.*

If at t a new idea has arrived and the firm decides to *stop* by not revealing the idea, the process ends. This is because of the assumed strong complementarity of the standardization process. If at t a new idea has arrived and the firm decides to either *disclose* or *continue* by sharing the idea with its competitor, in $t+1$ a new idea χ_{t+1} will arrive with probability p. With probability $1-p$, no new idea arrives, and the process stops—again, due to strict complementarity. Once the process ends, the firms' payoffs are materialized. The structure of the game is depicted in Figure 1.[16]

[FIGURE 1 ABOUT HERE]

[16]Note that only the part of the game tree with firm A having a patent is depicted as we are not interested in firm A's decision when he does not own a patent. (Firm B, when making her decision, however, will have to account for the possibility that firm A does not own a patent on χ_1. Because of the one-sidedness of the picture, firm B's information sets are not included.) As long as i has not disclosed, firm j forms posterior beliefs π_t^j as to whether firm i's initial technology is patent-protected. Firm j's posterior beliefs are given in brackets. Decision nodes without this bracket notation have posterior beliefs of $\pi_t^j = 1$ because i has disclosed the patent.

Figure 1: Conversation Game with Patent Disclosure



2.2 Payoffs

We assume that the value of the standard increases with the rounds of communication, as more rounds imply more ideas of standard improvement. We denote the number of ideas of improvement by $n_S \geq 0$. We use the *product market* setting in Stein (2008) and allow firms to collect *license fees* for their intellectual property, if existent.

2.2.1 Product Market

The firms are competitors in the market for homogeneous good. A better standard, with higher n_S, results in lower costs of production. More specifically, having access to an n_S-standard, the parties can manufacture the product at cost $1 - h(n_S)$.

ASSUMPTION 2. *$h(n_S)$ is increasing and continuous in n_S with $h(0) = 0$ and $\lim_{n_S \to \infty} h(n_S) = 1$.*

A firm that has a new idea for standard improvement, but decides not to communicate it, manufactures the product at cost $1 - h(n_S + 1) < 1 - h(n_S)$ and has a cost advantage over its rival because $n_i = n_S + 1 > n_S = n_j$, with $i, j = A, B$, $i \neq j$. Both firms produce the good under standard n_S, but firm i can produce at a lower cost due to an additional unrevealed idea. If, instead, the standardization process stops because a new idea does not arrive, then both firms have access to the same stock of ideas and $n_A = n_B = n_S$.

We assume that firms A and B each face a market of unit mass and that all customers have a reservation value of one. Moreover, there is a fractional overlap of size $\theta \in (0, 1)$ in A's and B's customer bases. In other words, firms 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.

These product market assumptions yield product market profits of

$$R_i = (1-\theta)\, h(n_i) + \theta \max\{0, h(n_i) - h(n_j)\}\,. \tag{1}$$

The first part of equation (1) reflects the fact that for a fraction $(1-\theta)$ of its customers, firm i is a monopolist and charges the full reservation value of one—with production costs of $1 - h(n_i)$. The profits of firm i per customer are thus $h(n_i)$. On the remaining fraction θ of its customer base—overlapping with j's customer base—firm i makes a profit only if its costs are strictly below those of j so that, by Bertrand competition, it can make a price offer below firm j's and $h(n_i) > h(n_j)$.

2.2.2 License Fees

If firm i owns a patent on one of the technologies incorporated into the standard, it can extract parts of firm j's market profits as license fee. This potential for license fees depends on whether or not firm i has disclosed its intellectual property and the underlying rules of disclosure set by the standard-setting organization. We will consider two regimes.

DEFINITION 1 (Disclosure Rules)**.**

- No-Waiver Regime: *Firms must disclose intellectual property of* $\chi_{t_i^0}$ *before or after the standardization process has come to an end.*

- Waiver Regime: *Firms must disclose intellectual property before the standardization process comes to an end. If patents on* $\chi_{t_i^0}$ *have not been disclosed, i.e., if disclosure is not timely, these are considered to be waived.*

The license fee firm i can extract from firm j depends on whether the firm has timely disclosed (according to the disclosure rules), the degree of lock-in of firm j, and the resulting bargaining leverage for firm i (i.e., *holdup*). Suppose firm i has disclosed timely, then $\sigma_i : (0,1) \times T_i \to [0,1]$ is the fraction of firm j's profits firm i can extract by means of license fees. It depends on (1) the strength $\alpha_i \in (0,1)$ of the patent of firm i; and (2) the timing $\tau_i \in T_i$ of firm i's disclosure.

ASSUMPTION 3 (License Fees)**.**

1. *$\sigma_i(\alpha_i, \tau_i)$ is continuous and increasing in $\alpha_i \in [0,1]$ and $\tau_i \in T_i$;*
2. *$\sigma_i(\alpha_i, \tau_i) > 0$ if and only if $\alpha_i > 0$ and $\tau_i > t_i^0$; $\sigma_i(0, \tau_i) = \sigma_i(\alpha_i, t_i^0) = 0$ otherwise;*
3. *$\lim_{t\to\infty} \sigma_i(\alpha_i, t) = \alpha_i < 1$;*
4. *If in the waiver regime disclosure of firm i is not timely, then $\sigma_i(\alpha_i, \tau_i) = 0$.*

The positive effect of α_i on $\sigma_i(\alpha_i, \tau_i)$ captures the idea that firm i's bargaining leverage over j will depend on how weak or strong the patent is expected to be (Farrell and Shapiro, 2008). The positive effect of τ_i on $\sigma_i(\alpha_i, \tau_i)$ reflects the impact of lock-in into a standard. As more and more ideas for improvement, χ_t, are added to the standard, on top of patent-protected technologies χ_1 and χ_2, the longer the standardization process continues, and the more likely firms will have invested in relationship-specific assets, in reliance on the standard to be approved.[17] Th fraction of firm j's profits that firm i can extract is bounded by i's patent strength, α_i.

Market profits R_i in (1) are the firms' overall profits when σ_i and σ_j are equal to zero. We denote the firms' utility when accounting for license fees by U_i: $U_i(i,j)$ is firm i's utility when both i and j have timely disclosed their intellectual property; $U_i(i,0)$ is firm i's utility when i has timely disclosed and j does not own intellectual property or has not timely disclosed (in the waiver regime); $U_i(0,j)$ is firm i's utility when i

[17] See the discussion of the Belkin case in the introduction.

has not timely disclosed (in the waiver regime) and j has timely disclosed; finally, $U_i(0,0) = R_i$.

$$\begin{aligned} U_i(i,j) &= (1-\sigma_j(\alpha_j,\tau_j))\,R_i + \sigma_i(\alpha_i,\tau_i)R_j, \quad (2)\\ U_i(i,0) &= R_i + \sigma_i(\alpha_i,\tau_i)R_j, \quad (3)\\ U_i(0,j) &= (1-\sigma_j(\alpha_j,\tau_j))\,R_i + R_j. \quad (4)\end{aligned}$$

3 First Best and Cooperative Equilibrium

In a first-best world, both firms communicate their respective ideas for standard improvement until a new idea fails to arrive. This maximizes the expected number of ideas, n_S, and minimizes production costs. Whether or not the firms disclose their intellectual property has no impact on this expected value; disclosure has no social value. This is because given a standard n_S and possible cost-advantage for one firm, $n_S + 1$, we find that

$$\begin{aligned} U_A(A,B)+U_B(B,A) = U_A(A,0)+U_B(0,A) &= \\ U_A(0,B)+U_B(B,0) = U_A(0,0)+U_B(0,0) &= R_A + R_B. \quad (5)\end{aligned}$$

Before we analyze the firms' incentives when standardization is non-cooperative, we first consider standardization as a cooperative process and ask under what conditions the first-best scenario can be implemented as cooperative equilibrium.

If the firms communicate their ideas until a new idea fails to arrive, then both have the same number of ideas, n_S, and their joint payoffs are

$$R_A + R_B = 2\,(1-\theta)\,h(n_S). \quad (6)$$

If firm i at some point decides to stop rather than reveal a new idea, then $n_i = n_j + 1$. Their joint payoffs in this case are

$$R_i + R_j = h(n_i) + (1 - 2\theta)\, h(n_j). \tag{7}$$

We show in the following proposition that disclosure and communication of ideas are not part of a cooperative equilibrium if θ is sufficiently high, with the critical value strictly larger than $1/2$. In other words, in a highly competitive industry, standard setting cannot be sustained as cooperative equilibrium.

PROPOSITION 1 (Cooperative Equilibrium)**.** *For sufficiently high values of θ so that competition is too high, there is no communication in the cooperative equilibrium. This critical value for θ is strictly larger than $1/2$.*

For the remainder of this paper we restrict attention to sufficiently low degrees of competition. 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 sections.

4 Post-Disclosure Communication

We first analyze the firms' incentives to continue communication after all patents have been disclosed, i.e., for $t > \max\{\tau_i, \tau_j\}$. The analysis is analogous to the steps in Stein (2008:2154-5) but for firm i extracting fraction $\sigma_i(\alpha_i, \tau_i)$ of j's profits. In Proposition 2 we summarize the main results for post-disclosure communication: continued communication by both firms until a new idea fails to arrive is easier to sustain in the presence of own intellectual property.

Assume both firms have disclosed their patents at stage τ_i and τ_j, respectively. If in period $t > \max\{\tau_i, \tau_j\}$ a new idea arrives, firm i either continues or stops. Suppose both firms always continue until a new idea fails to arrive, then firm i's expected payoffs are given by

$$\mathrm{E}_t U_i(continue@t|\tau_i, \tau_j) = [1 - \sigma_j(\alpha_j, \tau_j) + \sigma_i(\alpha_i, \tau_i)]\,(1-\theta)\,H(t) \tag{8}$$

where

$$H(t) = \sum_{k=0}^{\infty} p^k\,(1-p)\,h(t+k) \tag{9}$$

is increasing in p.[18] With probability $(1-p)$, there will be no further ideas after time t, so the standard has $n_S = t$ components with a total cost-reducing value of $h(t)$ for both firms; with probability $p\,(1-p)$, there will be exactly one further idea after t, so the standard has $t+1$ components with a total cost-reducing value of $h(t+1)$; with probability $p^2\,(1-p)$ there are exactly two further ideas, and so forth.

By contrast, suppose that firm i chooses to stop at stage t. The firm's payoffs in this case are equal to

$$U_i(stop@t|\tau_i, \tau_j) = (1 - \sigma_j(\alpha_j, \tau_j))\,[h(t) - \theta h(t-1)] + \sigma_i(\alpha_i, \tau_i)(1-\theta)h(t-1). \tag{10}$$

This expression reflects the fact that if firm i keeps idea χ_t to itself and has therefore a production cost advantage over j. This allows firm i to not only earn a profit of $(1-\theta)\,h(t)$ in the monopoly market, but also a profit of $\theta\,[h(t) - h(t-1)]$ in the competitive market, in which i underbids firm j by offering a price $1 - h(t-1)$ that is equal to firm j's production costs. Because of j's license fees, firm i keeps only a

[18]The derivative of $H(t)$ with respect to p is equal to $\sum_{k=0}^{\infty} p^k \left(\frac{k(1-p)}{p} - 1\right) h(t+k)$, which, after some manipulation, can be rewritten as $\sum_{k=0}^{\infty} (1+k)\,p^k\,[h(t+k+1) - h(t+k)] > 0$ for all $p > 0$.

fraction $1 - \sigma_j(\alpha_j, \tau_j)$ of its profits. In addition, firm i extracts a fraction $\sigma_i(\alpha_i, \tau_i)$ of j's profits $(1-\theta)\, h(t-1)$ in j's monopoly market.

For firm i to always continue the standardization process until a new idea fails to arrive, $\mathrm{E}_t U_i(\mathit{continue}@t|\tau_i, \tau_j) \geq U_i(\mathit{stop}@t|\tau_i, \tau_j)$ must hold for all values of $t > \max\{\tau_i, \tau_j\}$. This condition can be rearranged to read

$$\left(1 + \frac{\sigma_i(\alpha_i, \tau_i)}{1 - \sigma_j(\alpha_j, \tau_j)}\right) \frac{H(t) - h(t-1)}{h(t) - h(t-1)} \geq \frac{1}{1-\theta}. \tag{11}$$

Note that in absence of firm i's intellectual property the condition for the standardization process to continue reads as condition (6) in Stein (2008), that is

$$\frac{H(t) - h(t-1)}{h(t) - h(t-1)} \geq \frac{1}{1-\theta}. \tag{12}$$

A comparison of conditions (11) and (12) gives the impression that the presence of firm i's intellectual property improves communication incentives. However, to establish the impact of $\sigma_i(\alpha_i, \tau_i)$ and $\sigma_j(\alpha_j, \tau_j)$ on the relative gains from continue the process versus stop it is more appropriate to compute how the difference between (8) and (10) varies with the value $\sigma_i(\alpha_i, \tau_i)$ and $\sigma_j(\alpha_j, \tau_j)$. This is what we do to establish the comparative statics results in Proposition 2.

PROPOSITION 2 (Post-Disclosure Communication)**.** *If condition* (11) *is satisfied for all values of* $t > \max\{\tau_i, \tau_j\}$ *and* $i, j = A, B$*, then firms will continue the standardization process until a new idea fails to arrive. Firm* i*'s communication incentive constraint is less binding the stronger its own intellectual property and the later it has disclosed its patent. Existence of firm* j*'s patent renders firm* i*'s communication incentives more binding if* (12) *is satisfied.*

After both patents have been disclosed, firm i's communication incentives increase with its own patent strength and holdup potential (reflected by $\sigma_i(\alpha_i, \tau_i)$). After the firm has disclosed its patent, it can enforce its intellectual property by extracting a fee whose total value increases with the value of the standard and thus the duration of the standardization process. The existence of j's intellectual property, on the other hand, reduces firm i's profits from both continue in equation (8) and stop in equation (10). We show that as long as (12) is satisfied, the marginal decrease in firm i's payoffs from continue is larger than the marginal reduction in the payoffs from stop. This implies that the gains from continuing the process are lower.

The intuition for the result that an increase in $\sigma_j(\alpha_j, \tau_j)$ reduces i's gains from continue is straightforward. It is related to the exacerbation of the expropriation conduct faced by firm i. We also find that an increase in $\sigma_j(\alpha_j, \tau_j)$ can increase the gains from continue. However, this is only possible if, in the baseline case without intellectual property, firm i doees not find it profitable to continue the conversation (that is, when (12) is violated).

5 Unconstrained Patent Disclosure

In this section we analyze how patent disclosure and the scope for holdup (by way of license fees that increase with late disclosure) affect the firms' incentives to communicate in a standardization process *before* patents have been disclosed. We start with the simplifying assumptions that (1) after disclosure, both firms always continue the conversation (that is, (11) holds true) and (2) before disclosure by firm i, firm j will always continue and firm i's disclosure decision is *unconstrained* by j's behavior. In Section 6 we explicitly account for j's communication incentves to study firm i's *constrained* disclosure decision.

We ask the following: do firms ever have an incentive to delay disclosure? And if so, what are the conditions for such delayed disclosure? We look at both the no-waiver regime and the waiver regime, so to draw a comparison between the consequences of each rule on firms' behavior in standard setting.

5.1 No-Waiver Regime

The no-waiver regime implies that if, by the time *(a)* a new idea fails to arrive in period t or *(b)* one of the firms decides to *stop*, firm i has not yet disclosed its patent, it can do so *ex post* in t so that $\sigma_i(\alpha_i, t)$. Since there are no costs attached to late disclosure in the no-waiver regime, firms who have not disclosed will find it profitable to disclose once the standardization process has stopped. Moreover, as we show in Proposition 3, firms will always delay disclosure of their patents and disclose once the process has come to an end.

PROPOSITION 3 (Disclosure in No-Waiver Regime)**.** *In the no-waiver regime, if it has a patent, firm i will always disclose after the standardization process has been stopped or a new idea has failed to arrive.*

The reason for this is straightforward and a formal proof omitted. Once firm i has disclosed in τ_i, the fraction of firm j's profits it can extract is $\sigma_i(\alpha_i, \tau_i)$. Continuing communication increases the value of the standard and thus the firms' market profits, whereas fraction $\sigma_i(\alpha_i, \tau_i)$ is fixed for all $t \geq \tau_i$. Since $\sigma_i(\alpha_i, \tau_i)$ is increasing in τ_i and late disclosure does not come at a cost, firm i strictly prefers later disclosure over early disclosure. The latest disclosure date possible is when the process has come to an end.[19]

[19] Proposition 3 implies that—given the communication condition in (17) below is satisfied—the expected disclosure date coincides with the expected duration of the standardization process, $E_1\tau_i = 1 + \sum_{i=0}^{\infty} p^i(1-p)i = \frac{1}{1-p}$.

By Proposition 3, disclose is strictly dominated by continue for both i and j. To determine the condition for which firm i will continue and not stop,

$$\mathrm{E}_t U_i^{NW}(\mathit{continue}@t) \geq U_i^{NW}(\mathit{stop}@t), \tag{13}$$

suppose continue is the equilibrium strategy for both firms. Then by Proposition 3, they will disclose once a new idea fails to arrive and firm i's expected payoffs, at t, in the no-waiver regime are

$$\mathrm{E}_t U_i^{NW}(\mathit{continue}@t) = (1-\theta)\,\bar{H}(t) \tag{14}$$

with

$$\bar{H}(t) = H(t) + \sum_{k=0}^{\infty}\left[\sigma_i(\alpha_i, t+k) - \pi_t^i \sigma_j(\alpha_j, t+k)\right] p^k\,(1-p)\,h(t+k). \tag{15}$$

Both $\sigma_i(\alpha_i, t)$ and $\sigma_j(\alpha_j, t)$ increase as the process continues and disclosure is delayed. Expectations are taken both over the arrival of new ideas (with probability p) and firm j having a patent. Note that firm i, if it has a patent, will extract $\sigma_i(\alpha_i, t)$ from firm j's profits, and firm i anticipates, at t, that firm j has a patent with π_t^i. Firm j extracts $\sigma_j(\alpha_j, t)$ of i's profit with this probability π_t^i.

Firm i's expected payoffs from stop in t, so that $\sigma_i(\alpha_i, t)$ and $\sigma_j(\alpha_j, t)$, are

$$U_i^{NW}(\mathit{stop}@t) = \left(1 - \pi_t^i \sigma_j(\alpha_j, t)\right)\left[h(t) - \theta h(t-1)\right] + \sigma_i(\alpha_i, t)(1-\theta)h(t-1). \tag{16}$$

Firm i always continues and discloses once a new idea fails to arrive if condition (13), rewritten as

$$\frac{\bar{H}(t) - (1 + \sigma_i(\alpha_i, t) - \pi_t^i \sigma_j(\alpha_j, t))h(t-1)}{(1 - \pi_t^i \sigma_j(\alpha_j, t))(h(t) - h(t-1))} \geq \frac{1}{1-\theta}. \tag{17}$$

holds true for all t. We summarize the pre-disclosure communication incentives in the no-waiver regime in the following proposition.

PROPOSITION 4 (Communication in No-Waiver Regime)**.** *If condition (17) is satisfied for all t and $i, j = A, B$, then in the no-waiver regime firms will continue the standardization process until a new idea fails to arrive, and only then disclose their patents. Firm i's communication incentive constraint is less binding the stronger its own intellectual property. Existence of firm j's intellectual property reduces firm i's communication incentives if*

$$(1-\theta)\sum_{k=0}^{\infty} \sigma_j(\alpha_j, t+k) p^k (1-p) h(t+k) \geq \sigma_j(\alpha_j, t) [h(t) - \theta h(t-1)].$$

As for the post-disclosure communication incentives (analyzed in Proposition 2), the existence of own intellectual property increases firms' incentives to continue the standardization process. Conversely, the existence of firm j's patent lowers firm i's incentives whenever an increase in $\sigma_j(\alpha_j, \tau_j)$ triggers a reduction of firm i's exptected payoffs from continue in equation (14) that outweighs the decrease of its payoffs from stop in equation (16).

5.2 Waiver Regime

For the remainder of the paper we consider the waiver regime: if firms have not disclosed their intellectual property by the time the standardization process comes to an end, their patents are invalid. Unlike in the no-waiver regime, delaying disclosure, say from

t to $t+2$, comes at a cost. Given that firm j's communication incentives are not binding (it will always continue), with probability $1-p^2$ firm i will not reach stage $t+2$ and will thus not get to disclose. It will then lose its bargaining leverage and fraction $\sigma_i(\alpha_i, t)$ of j's profits. Conversely, by not delaying but disclosing in t, firm i foregoes some license fees because $\sigma_i(\alpha_i, t) < \sigma_i(\alpha_i, t+2)$. In what follows below, we show how firm i solves this tradeoff. We first consider the scenario where firm j has not yet disclosed (firm i's decision to disclose before j discloses) and then proceed to the case where firm j's has disclosed (firm i's decision to disclose after firm j).

5.2.1 Firm i Discloses Before Firm j

Our approach to firm i's disclosure decision is as follows: because at any t, firms cannot commit to disclose at any $t+k$, $k \geq 2$, firm i can either stop, disclose, or continue and reconsider the disclosure decision in $t+2$. It will delay disclosure if and only if its expected payoffs from disclosure in $t+2$ (continue in t and disclose in $t+2$), $\mathrm{E}_t U_i^W(disclose@t+2)$, are at least as high as the expected payoffs from disclosure in t, $\mathrm{E}_t U_i^W(disclose@t)$. Because of the lack of commitment, this does not imply that firm i indeed discloses in $t+2$, but it will then reconsider its decision and again delay disclosure if and only if $\mathrm{E}_{t+2} U_i^W(disclose@t+4) \geq \mathrm{E}_{t+2} U_i^W(disclose@t+2)$; and so forth.

Firm i's expected payoffs from disclosure in t (when both firms continue after disclosure, i.e., when post-disclosure communication condition (11) is satisfied) are

$$\mathrm{E}_t U_i^W(disclose@t) = (1-\theta)\left[H(t) + \sigma_i(\alpha_i, t)H(t) - \pi_t^i H(t, \tau_j)\right]. \qquad (18)$$

If firm i expects firm j to have no patent (with probability $1-\pi_t^i$), then both firms generate market profits of $(1-\theta)\,H(t)$, where firm i is able to extract a fraction of

$\sigma_i(\alpha_i, t)$ of firm j's market profits. With probability π_t^i firm i expects j to have a patent, in which case firm j is able to extract

$$H(t, \tau_j) = p^{\tau_j - t} \sigma_j(\alpha_j, \tau_j) H(\tau_j) \tag{19}$$

of firm i's market profits—given an anticipated disclosure date τ_j. Firm i's expected payoffs from delayed disclosure in $t+2$ are

$$\mathrm{E}_t U_i^W(disclose@t+2) = (1-\theta)\left[H(t) + p^2 \sigma_i(\alpha_i, t+2) H(t+2) - \pi_t^i H(t, \tau_j)\right]. \tag{20}$$

The payoffs from stop at t are

$$U_i^W(stop@t) = h(t) - \theta h(t-1). \tag{21}$$

For the results below we assume that both firms' communication constraints are satisfied. This implies that firm i will continue and delay disclosure for all t as long as

$$\mathrm{E}_t U_i^W(disclose@t+2) \geq \mathrm{E}_t U_i^W(disclose@t).$$

In Lemma 1 we show that with a valid patent, $\alpha_i > 0$, firm i will always delay disclosure. This means, firm i's disclosure date is $\tau_i \geq t_i^0 + 2$. This is because i's payoffs from disclosure in $t = t_i^0$ are strictly smaller than the payoffs from continuing and disclosing in $t = t_i^0 + 2$.

LEMMA 1. *Given anticipated disclosure τ_j by firm j, firm i delays disclosure of its patent so that $\tau_i \in T_i \setminus \{t_i^0\}$ if and only if $\alpha_i > 0$.*

In the waiver regime, if the firm has a valid (but possibly weak) patent, it will not disclose immediately. Unlike in the no-waiver regime, however, the firms will not wait until the standardization process has come to an end. If the process allows, meaning if enough new ideas arrive, firm i will always find it optimal to disclose *before* the process stops. We refer to this date of disclosure as *aspired* disclosure date, τ_i^*. If the process comes to an end before this $t = \tau_i^*$, then the aspired disclosure date cannot be realized, and the patent is not disclosed. We summarize in Lemma 2.

LEMMA 2. *The aspired disclosure date, $\tau_i^* > t_i^0$, is finite.*

We can now characterize firm i's optimal aspired disclosure date in the waiver regime when communication incentives are not binding, i.e., the only reason why the standardization process stops is when a new idea fails to arrive.

PROPOSITION 5 (Unconstrained Disclosure)**.** *Let both firms' pre-disclosure communication incentives be satisfied. Firm i delays disclosure of valid intellectual property but plans to disclose at a finite stage τ_i^*. This aspired disclosure date τ_i^* is equal to the smallest $\hat{t}_i \in T_i \setminus \{t_i^0\}$ such that*

$$\mathrm{E}_t U_i^W(disclose@t) < \mathrm{E}_t U_i^W(disclose@t+2) \tag{22}$$

for all $t_i^0 \leq t < \hat{t}_i$, and $>$ for some $\hat{t}_i \leq t < \hat{t}_i + 2$.

Firm i's disclosure, if it has a patent, is timely, i.e., not subject to the implied waiver in Assumption 3, with probability $p^{\tau_i^*}$. In Corollary 1, we provide comparative statics for τ_i^*, reflecting firm i's propensity to delay disclosure with respect to p, α_i, α_j, and θ.

COROLLARY 1. *If $p > 1/2$ firm i's propensity to delay disclosure is increasing in the success probability p. Firm i's propensity to delay disclosure is increasing in firm*

i's patent strength α_i if and only if

$$\frac{\sigma_i^{\alpha_i}(\alpha_i, \hat{t}_i)}{\sigma_i^{\alpha_i}(\alpha_i, \hat{t}_i + 2)} \cdot \frac{H(\hat{t}_i)}{H(\hat{t}_i + 2)} < p^2 \tag{23}$$

where $\sigma_i^{\alpha_i}(\alpha_i, t)$ is the partial derivative of $\sigma_i(\alpha_i, t)$ with respect to α_i. Firm j's intellectual property, α_j, and the degree of market competition, θ, have no effect on firm i's aspired disclosure date.

These results warrant a few words of discussion. First, firm i is more likely to delay disclosure the higher the probability of new ideas arriving. A higher p increases both the expected profits from disclosing in t and the payoffs from disclosing in $t+2$. Indeed, if firm i decides to delay disclosure in t, the associated costs of not arriving in $t+2$ and thus losing the license fees due to the implied waiver are lower.[20] We show that if the baseline value of p is sufficiently high (that is, higher than 1/2), then the propensity to delay disclosure increases in p. Second, a stronger patent increases the gains from disclosing in t and from disclosing in $t+2$, where the latter are discounted by arrival probability p^2. Condition (23) implies that if the difference of marginal license fees in $t+2$ and t is sufficiently large to offset the costs of time, p^2, higher patent strength results in later delay.

The results in Proposition 5 apply to the situation where both firms' communication constraints are satisfied, i.e., both firms will not stop the standardization process. This means, before disclosure, not only are the expected payoffs from delaying at least as high as the expected payoffs from immediate disclosure in t, but expected payoffs from delaying disclosure in (20) must be at least as high as the payoffs from stopping in

[20] This is because the probability $1 - p^2$ of not reaching $t + 2$ is decreasing in p.

(21). This is the case if

$$\frac{H(t) - h(t-1) + p^2\sigma_i(\alpha_i, t+2)H(t+2) - \pi_t^i H(t, \tau_j)}{h(t) - h(t-1)} \geq \frac{1}{1-\theta}. \tag{24}$$

A firm's own intellectual property thus relaxes its communication constraint, whereas firm j's intellectual property (both beliefs π_t^i and license fee $\sigma_j(\alpha_j, \tau_j)H(\tau_j)$) renders the constraint more binding, as can be seen when using the expression for $H(t, \tau_j)$ in (19).

Condition (24) can be rewritten for firm j. We discuss in Section 6 how this communication restriction on j's side will affect firm i's optimal aspired patent disclosure.

5.2.2 Firm i Discloses After Firm j

We now consider the case in which firm j has already disclosed the patent, so that $\pi_t^i = 1$ for all $t > \tau_j$, when firm i faces this decision. Firm i's payoffs in $t \geq \tau_j + 1$ are

$$\begin{aligned} \mathrm{E}_t U_i^W(disclose@t|\tau_j) &= (1-\theta)\left[H(t) + (\sigma_i(\alpha_i, t) - \sigma_j(\alpha_j, \tau_j))\, H(t)\right] && (25) \\ \mathrm{E}_t U_i^W(disclose@t+2|\tau_j) &= (1-\theta)\big[H(t) + p^2\sigma_i(\alpha_i, t+2)H(t+2) \\ &\quad - \sigma_j(\alpha_j, \tau_j)H(t)\big] && (26) \\ U_i^W(stop@t|\tau_j) &= (1 - \sigma_j(\alpha_j, \tau_j))\left[h(t) - \theta h(t-1)\right] && (27) \end{aligned}$$

for disclose at t, for continue and disclose at $t+2$, and for stop at t.

Again, for the results that follow we assume that both firms' communication constraints are satisfied and stop is dominated by communication. This implies that firm i will continue and delay disclosure for all $t > \tau_j$ as long as

$$\mathrm{E}_t U_i^W(disclose@t+2|\tau_j) \geq \mathrm{E}_t U_i^W(disclose@t|\tau_j).$$

Lemma 3 that shows delayed disclosure is analogous to Lemma 1. Note that because firm i discloses once firm j discloses, firm $i = A$ will always delay disclosure by this assumption. In the lemma we show that firm $i = B$ delays disclosure because it is optimal to do so.

LEMMA 3. *Given disclosure by firm A in τ_A, firm B delays disclosure of its patent so that $\tau_B > t_B^0$.*

Lemma 4 is analogous to Lemma 2.

LEMMA 4. *Given disclosure by firm j in τ_j, the aspired disclosure date of firm i, $\tau_i^*(\tau_j) > t_i^0$, is finite.*

We can now summarize firm i's disclosure decision in the waiver regime once firm j has disclosed.

PROPOSITION 6 (Unconstrained Disclosure in $t > \tau_j$)**.** *Suppose firm j has disclosed in τ_j and let both firms' pre-disclosure communication constraints be satisfied for all $t > \tau_j$. Firm i discloses its valid intellectual property at a finite stage $\tau_i^*(\tau_j)$. This aspired disclosure date $\tau_i^*(\tau_j)$ is equal to the smallest $\hat{t}_i \in T_i \setminus \{t : t \in T_i, t \leq \tau_j\}$ such that*

$$\mathrm{E}_t U_i^W(\textit{disclose@}t|\tau_j) < \mathrm{E}_t U_i^W(\textit{disclose@}t+2|\tau_j) \tag{28}$$

for all $\tau_j < t < \hat{t}_i$, and $\geq$ for some $t \geq \hat{t}_i$.

We show in Corollary 2 that disclosure by j does not affect firm i's aspired disclosure date. It follows that the comparative statics from Corollary 1 for τ_i^* also apply to $\tau_i^*(\tau_j)$.

COROLLARY 2. $\tau_i^* = \tau_i^*(\tau_j)$ *for all $t_j^0 < \tau_j < \tau_i^*(\tau_j)$.*

As for the firm's communication incentive constraints: we studied firm i's communication incentives in Section 4 and provided firm i's constraint in condition (11). The same condition applies to firm j after firm both firms have disclosed. The incentives for firm j before i discloses are given in equation (24) for firm j instead of i.

6 Constrained Patent Disclosure in Waiver Regime

The results in Propositions 5 and 6 present firm i's planned or *aspired* date of disclosure in the waiver regime when it expects firm j to always continue so that the standardization process stops only if a new idea fails to arrive. Firm i is thus *unconstrained* in the sense that firm j's actions will not affect its optimal disclosure decision. In this section, we now explicitly account for j's communication incentives and study how the threat of firm j stopping the standardization process affects firm i's disclosure decision.

We again consider the scenario in which firm i discloses before firm j under a waiver regime. Firm j will continue the standardization process and reveal any new idea as it arrives if

$$\frac{H(t) - h(t-1) + p^2\sigma_j(\alpha_j, t+2)H(t+2) - \pi_t^j H(t, \tau_i)}{h(t) - h(t-1)} \geq \frac{1}{1-\theta} \tag{29}$$

holds true given anticipated disclosure by firm i at stage τ_i.[21] Let

$$\pi_t^{j*}(\tau_i) = \frac{(1-\theta)\left[H(t) + p^2\sigma_j(\alpha_j, t+2)H(t+2)\right] - \left[h(t) - \theta h(t-1)\right]}{(1-\theta)\, H(t, \tau_i)} \tag{30}$$

be defined such that (29) holds for all $\pi_t^j \leq \pi_t^{j*}(\tau_i)$ (and with strict equality for $\pi_t^j = \pi_t^{j*}(\tau_i)$). Intuitively, firm j is the more inclined to continue the standardization process the lower is its belief π_t^j that firm i owns a patent. $\pi_t^{j*}(\tau_i) \geq 0$ if

$$\frac{H(t) - h(t-1) + p^2\sigma_j(\alpha_j, t+2)H(t+2)}{h(t) - h(t-1)} \geq \frac{1}{1-\theta} \tag{31}$$

[21] Condition (29) for firm j is the analogous to condition (24) for firm i.

($\pi_t^{j*}(\tau_i) = 0$ if (31) holds with equality), and $\pi_t^{j*}(\tau_i) \leq 1$ if

$$\frac{H(t) - h(t-1) + p^2 \sigma_j(\alpha_j, t+2) H(t+2) - H(t, \tau_i)}{h(t) - h(t-1)} \leq \frac{1}{1-\theta} \tag{32}$$

($\pi_t^{j*}(\tau_i) = 1$ if (32) holds with equality). Moreover, $\pi_t^{j*}(\tau_i) \in (0, 1)$ if both (31) and (32) hold with strict inequality. Conditions (31) and (32) give rise to the three following cases:

Case 1: Both condition (31) and condition (32) are satisfied so that $\pi_t^{j*}(\tau_i) \in [0, 1]$. Firm j continues in t if $\pi_t^j \leq \pi_t^{j*}(\tau_i)$ and stops otherwise.

Case 2: Condition (31) is satisfied and condition (32) is violated so that $\pi_t^{j*}(\tau_i) > 1$. Firm j continues in t for all $\pi_t^j \in [0, 1]$.

Case 3: Condition (31) is violated and condition (32) is satisfied so that $\pi_t^{j*}(\tau_i) < 0$. No $\pi_t^j \in [0, 1]$ exists such that firm j continues in t.

We are interested in how firm j's communication incentives (summarized by the three cases above) affect firm i's patent disclosure decision. For that we assume that firm i indeed has a patent and that its communication incentives in (24) are satisfied for $t \leq \tau_i^*$, i.e., it is willing to continue the standardization process until τ_i^*. Note that firm j's behavior in the three cases depends on its beliefs π_t^j in t. If it believes firm i to not be a patent holder, firm j expects firm i to continue if

$$\frac{H(t) - h(t-1) - \pi_t^i H(t, \tau_j)}{h(t) - h(t-1)} \geq \frac{1}{1-\theta} \tag{33}$$

and condition (33) is more restrictive than (24). This implies that if (33) is violated, but firm i continues, then it must be the case that firm i indeed holds a patent; and firm j updates its beliefs accordingly.

In Lemma 5, we characterize the Perfect Bayesian Equilibrium of the disclosure game depicted in Figure 1 in *cases 1* and *2* and assuming that (33) holds, so that firm j cannot infer from firm i's decision to continue whether or not firm i is a patent holder. The equilibrium disclosure stage, denoted by $\tilde{\tau}_i$, is such that firm j continues for all $t \leq \tilde{\tau}_i - 1$, firm i discloses at $t = \tilde{\tau}_i$, and firm j's beliefs are consistent with firm i's choices. We assume that both firms will continue after disclosure; condition (11) holds for both i and j for all $t > \max\{\tilde{\tau}_i, \tilde{\tau}_j\}$.

LEMMA 5 (Cases 1 and 2)**.** *Let the firms' post-disclosure communication constraints in* (11) *be satisfied. Moreover, let condition* (33) *be satisfied for all* $t < \tau_i^*$*, where* τ_i^* *is the aspired disclosure date defined in Proposition* 5*. In* Case 1*, equilibrium disclosure is at stage* $\tilde{\tau}_i \leq \tau_i^*$ *where* $\tilde{\tau}_i$ *is the highest* $\tau_i' \geq t_i^0 + 2$ *such that*

$$\pi^j \leq \min\left\{\pi^{j*}_{t_j^0+k}(\tau_i') : \ \forall t_j^0 + k < \tau_i' \textit{ with even } k \geq 0\right\}.$$

If no such $\tau_i' > t_i^0$ *exists, then disclosure is not delayed,* $\tilde{\tau}_i = t_i^0$*. In* Case 2*, equilibrium disclosure* $\tilde{\tau}_i$ *is at stage* τ_i^**.*

Case 1 has the potential to give rise to *constrained* disclosure by firm i, while in *case 2* firm j's communication incentives are not an issue (as was our working assumption in the previous section). The intuition for the result relative to *case 1* in Lemma 5 is straightforward. First, note that firm i will disclose at some stage t' if it anticipates that firm j will stop in $t' + 1$. Otherwise, firm i will lose its intellectual property due to the implied waiver in the waiver regime. Firm j will not stop but continue only if its beliefs $\pi^j_{t'+1}$ are sufficiently low, i.e., below the critical value in (30). Now, if at stage $t = 1$, firm i continues, then firm j cannot update its beliefs because both the patent holder firm i (with prior probability π^j) and, by (33), the non-patent holder firm i (with prior probability $1 - \pi^j$) will continue. In that case, firm j's posterior at

$t = 2$ is equal to the prior, π^j. In $t = 3$, if firm i anticipates that this π^j is less than $j's$ critical value in $t = 4$, firm i will continue in $t = 3$. Again, firm j cannot update beliefs, and the posterior in $t = 4$ is equal to j's prior belief. Firm i will wind up postponing disclosure as much as possible (but not later than τ_i^*) and disclose at the last stage for which the prior does not exceed j's critical value, $\pi_t^{j*}(\tilde{\tau}_i)$, that is evaluated at this equilibrium disclosure stage.

In Lemma 6, we discuss *case 3* in which (31) is violated for all $t < \tau_i^*$. This implies that (33) is violated, because (33) is more stringent than (31).

LEMMA 6 (Case 3)**.** *Let* (11) *be satisfied, and let* (33) *be violated for all* $t < \tau_i^*$ *where* τ_i^* *is the aspired disclosure date defined in Proposition 5. In* case 3 *equilibrium disclosure* $\tilde{\tau}_i$ *is at stage* t_i^0*.*

The result in Lemma 6 has implications for the impact of the degree of product market competition on disclosure. For degrees of competition sufficiently high, such that (32) is satisfied, but (31) and (33) are violated, we observe immediate disclosure. Firm i forsakes its rent-seeking possibilities to disclose. The intuition is that if competition is sufficiently fierce, firm j's monopoly profits are relatively low. Because firm i can extract rents only from j's monopoly profits—the parties' profits from the market on which they compete are small—if competition is fierce the gains from license fees are small and more than outweighed by the expected costs of losing license fees from the implied waiver.

Finally, in Lemma 7, we characterize the equilibrium disclosure decision if (31) and (32) are satisfied for all $t < \tau_i^*$, but (33) is violated for *some* $t < \tau_i^*$.

LEMMA 7. *Consider* case 1 *and let condition* (33) *be violated for some* $t < \tau_i^*$*, where* τ_i^* *is the aspired disclosure date defined in Proposition 5. Two cases can be distinguished:*

(a) *If there exists an integer* $t' \geq t_i^0$ *such that* (33) *is violated for* $t \leq t'$ *and* (33) *is satisfied for all* $t > t'$*, then equilibrium disclosure* $\tilde{\tau}_i$ *is at stage* τ_i^**.*

(b) *If there exists an integer* $t' > t_i^0$ *such that* (33) *is satisfied for* $t \leq t'$ *and* (33) *is violated for all* $t > t'$*, and* $\pi^j \leq \min\left\{\pi^{j*}_{t_j^0+k}(t') : \forall t_j^0 + k \leq t' \text{ with even } k \geq 0\right\}$*, but* $\pi^j > \pi^{j*}_{t'+1}(\tau_i^*)$*, then equilibrium disclosure* $\tilde{\tau}_i$ *is at stage* $\tilde{\tau}_i = t'$*. Conversely, if* $\pi^j \leq \pi^{j*}_{t'+1}(\tau_i^*)$ *then equilibrium disclosure* $\tilde{\tau}_i$ *is at* τ_i^**.*

Lemma 7 completes the analysis of the cases in which firm j's communication incentives can constrain firm i disclosure decision.[22] In Lemma 6, although (33) is violated, disclosure is never delayed because (32) is always violated and thus communication is not sustainable. In Lemma 7, (32) is satisfied. So, in the range of values of t in which (33) is violated firm j exploits the fact that a non-patent holder does not continue in order to screen firm i's type. In sub-case *(a)* this leads to unconstrained disclosure, whereas in sub-case *(b)* equilibrium disclosure is at the lowest $t = \tau_i'$ such that communication can be sustained.

PROPOSITION 7. *Condition* (31) *is a necessary condition for equilibrium disclosure to be unconstrained in an environment with Bayesian updating. If* (31) *holds, firm* j *has incentive to participate in the standardization process even when it expects firm* i *to be a patent holder.*

Proposition 7 uses the results in Lemmata 5, 6, and 7 to establish the necessary condition for disclosure to be at τ_i^*, as determined in Proposition 5, and unconstrained. In particular, if (31) is not satisfied (as in Lemma 6) disclosure at τ_i^* is unfeasible. However, even if (31) holds, Lemmata 5 and 7 show that disclosure may still not be at τ_i^*, depending on condition (33).

[22]For the case in which (31) holds whereas (32) and (33) are violated the analysis from *case 2* applies, and equilibrium disclosure $\tilde{\tau}_i$ is always at stage τ_i^*.

(31) is the condition that guarantees that the threshold value for j's beliefs ($\pi_t^{j*}(\tau_i)$) lies into the unit interval, so that if $\pi_t^j \leq \pi_t^{j*}(\tau_i)$ firm j is willing to sustain the standardization process even in the presence of a patent holder i_1. Due to the relevance of (31) in this setting, it is important to discuss how the validity of the condition is affected by three of the exogenous parameters of the model, p, α_j and θ, for a given equilibrium value of τ_i. On the one hand, an increase of the degree of competition, θ, restrains the validity of (31), by increasing the RHS of the condition. On the other hand, if α_j and p increase, the condition is relaxed. If α_j increases, then $\sigma_j(\alpha_j, t)$ increases, and so does the LHS of the inequality. Intuitively, a stronger patent of firm j increases the leverage bargaining power of firm j. Finally, the impact of the standardization baseline productivity, the arrival probability p, is straightforward as it increases the LHS of the condition. The intuition is that if the process productivity is higher, the incentive to continue is stronger.

Finally, the analysis of constrained disclosure in the scenario featuring firm i disclosing *after* firm j under a waiver regime is equivalent to the one above, in which firm i discloses *before* firm j under a waiver regime. Under the assumption that firm i continues the conversation until disclosure and ex-post communication incentives are sound, firm j will continue the standardization process if (29) and a non-patent holder i continues if (33). The relevant conditions are therefore qualitatively analogous to (30), (31), and (32), where the candidate for the *aspired* disclosure stage is as defined in Proposition 6 instead of Proposition 5.

7 Summary and Concluding Remarks

We present a model of standardization with two-sided asymmetric information about the existence of intellectual property. We provide an equilibrium analysis of (a) firms' incentives to communicate ideas for improvements of an industry standard and (b) firms' decisions to disclose the existence of intellctual property to other participants of the standardization process.

Communication Incentives: We find that a firm i's incentives to reveal ideas for stnadard improvement and thus continue the standardization process are spurred by the existence of its own intellectual property (see Propositions 2 and 4, and the discussion following (24)). Also, if the degree of product market competition θ rises, communication incentives become more binding, thereby threatening the sustainability of the standardization process.

Disclosure Decision: Two main regimes for the disclosure rule are considered, the waiver and the no-waiver regime. In the no-waiver regime, we find that disclosure takes place after the end of the standardization process. Conversely, for the waiver regime we find the following:

For unconstrained disclosure, we show that (1) firms want to strategically postpone disclosure provided their intellectual property is valid, and (2) they eventually plan to reveal the existence of respective intellectual property before the end of the process. The analysis of the propensity to disclose allows us to further qualify this result. First, we show that disclosure is more likely to be delayed in more productive, i.e., innovative, SSOs. Second, the strength of firm i's patent further delays disclosure if the gains from postponing (in terms of greater bargaining leverage) offset the cost of time (related to the likelihood that the process stops). Third, the strength of another firm j's patent has no impact on firm i's propensity to disclose. Fourth, disclosure is independent of the degree of market competition. For constrained disclosure, we investigate under which conditions the results derived in the unconstrained scenario remain valid. We provide a necessary condition for firm i's disclosure to be unconstrained in an environment with

Bayesian updating. In other words, there exists a non-empty range of values of firm j's beliefs for which the standardization process can continue up to firm i's aspired disclosure stage τ_i^*.

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A Appendix

Proof of Proposition 1

Proof. We assume a cooperative equilibrium exists, implying that communication (continue or disclose) of ideas for inprovement at all stages, until a new idea fails to arrive. We show that for sufficiently high θ the joint payoffs from continuing communication are smaller than from not continuing, i.e.,

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

for some t. The joint payoffs from continuing are

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

the joint payoffs from stopping are $U^C(\mathit{stop@t}) = h(t) + (1-2\theta)\,h(t-1)$. By $h(t) > h(t-1)$, $U^C(\mathit{stop@t}) > 0$ for all θ; $\mathrm{E}U^C(\mathit{continue@t}) = 0$ for $\theta = 1$ and strictly positive otherwise. The critical value $\theta^C(p, h(\cdot))$ (for which $\mathrm{E}U^C(\mathit{continue@t}) = U^C(\mathit{stop@t})$) is strictly smaller than unity so that there are some $\theta > \theta^C(p, h(\cdot))$ for which (A.1) holds. Note, also, that this critical value is strictly larger than 0.5. Suppose for a moment that

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

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

Proof of Proposition 2

Proof. The first part is by Proposition 2 in Stein (2008:2155). To assess the impact of $\sigma_i(\alpha_i, \tau_i)$ and $\sigma_j(\alpha_j, \tau_j)$ on communication incentives, rewrite the difference between (8) and (10) as

$$\begin{aligned}(1-\sigma_j(\alpha_j,\tau_j))\,[(1-\theta)\,H(t) - [h(t) - \theta h(t-1)]] + \\ \sigma_i(\alpha_i,\tau_i)\,(1-\theta)\,[H(t) - h(t-1)]\,.\end{aligned} \tag{A.2}$$

Claim 1: If $\sigma_i(\alpha_i, \tau_i)$ increases, then the difference in (A.2) increases because $h(t+k) > h(t-1)$ for all $k \geq 0$ (by $h(t)$ increasing in t in Assumption 2) and thus

$$H(t) = \sum_{k=0}^{\infty} p^k\,(1-p)\,h(t+k) > \sum_{k=0}^{\infty} p^k\,(1-p)\,h(t-1).$$

The positive effect of α_i and τ_i on $\sigma_i(\alpha_i, \tau_i)$ by Assumption 3 establishes the proof of the impact of $\sigma_i(\alpha_i, \tau_i)$.

Claim 2: If $\sigma_j(\alpha_j, \tau_j)$ increases, then (A.2) decreases if and only if

$$(1-\theta)\, H(t) - [(h(t) - \theta h(t-1)] \geq 0,$$

which is equivalent to

$$\frac{H(t) - h(t-1)}{h(t) - h(t-1)} \geq \frac{1}{1-\theta}.$$

The latter condition is equivalent to (12), establishing the proof. Q.E.D.

Proof of Proposition 4

Proof. As in the proof of Proposition 2, the first part of the claim is by Stein (2008:2155).

Claim 1: Firm i's intellectual property increases its communication incentives as the difference between (14) and (16) is higher for $\sigma_i(\alpha_i, t+k) > 0$ than for $\sigma_i(\alpha_i, t+k) = 0$ if

$$\begin{aligned}\sum_{k=0}^{\infty} \sigma_i(\alpha_i, t+k) p^k (1-p)\, h(t+k) \quad &\geq \quad \sigma_i(\alpha_i, t) \sum_{k=0}^{\infty} p^k (1-p)\, h(t+k) > \\ & \quad\ \sigma_i(\alpha_i, t) \sum_{k=0}^{\infty} p^k (1-p)\, h(t-1) = \sigma_i(\alpha_i, t) h(t-1),\end{aligned}$$

or, equivalently, if

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

which, as shown in the proof of Proposition 2, is positive for all $k \geq 0$.

Claim 2: Repeating the same exercise, we find that for $\sigma_j(\alpha_j, t+k) > 0$ firm i has weaker incentives to continue than for $\sigma_j(\alpha_j, t+k) = 0$, if

$$(1-\theta) \sum_{k=0}^{\infty} \sigma_j(\alpha_j, t+k) p^k (1-p)\, h(t+k) \geq \sigma_j(\alpha_j, t) [h(t) - \theta h(t-1)],$$

establishing the proof. Q.E.D.

Proof of Lemma 1

Proof. At $t = t_i^0$ (the first stage firm i gets to move), immediate disclosure by firm i yields expected payoffs of

$$\mathrm{E}_{t_i^0} U_i^W(disclose@t_i^0) = (1-\theta) \left[H(t_i^0) - \pi_{t_i^0}^i H(t_i^0, \tau_j)\right],$$

because $\sigma_i(\alpha_i, t_i^0) = 0$. Delaying disclosure one round, so that i discloses at $t = t_i^0 + 2$, yields expected payoffs (evaluated at $t = t_i^0$) of

$$\begin{aligned} \mathrm{E}_{t_i^0} U_i^W(\mathit{disclose}@t_i^0 + 2) &= (1-\theta)\left[H(t_i^0) + p^2 \sigma_i(\alpha_i, t_i^0 + 2) H(t_i^0 + 2) - \right. \\ &\qquad \left. \pi_{t_i^0}^i H(t_i^0, \tau_j)\right]. \end{aligned}$$

Disclose at $t = t_i^0$ is dominated by *disclose* at $t = t_i^0 + 2$ for all $\sigma_i > 0$ because $p > 0$ and

$$\begin{aligned} \mathrm{E}_{t_i^0} U_i^W(\mathit{disclose}@t_i^0) &= (1-\theta)\left[H(t_i^0) - \pi_{t_i^0}^i H(t_i^0, \tau_j)\right] \\ &< (1-\theta)\left[H(t_i^0) - \pi_{t_i^0}^i H(t_i^0, \tau_j)\right] + (1-\theta)\, p^2 \sigma_i(\alpha_i, t_i^0 + 2) H(t_i^0) \\ &= \mathrm{E}_{t_i^0} U_i(\mathit{disclose}@t_i^0 + 2). \end{aligned}$$

Q.E.D.

Proof of Lemma 2

Proof. For simplicity and without loss of generality, we assume that $t \in \left(t_i^0, \infty\right) \subset \mathbb{R}_+$. Consider the following properties of the expected payoff functions $\mathrm{E}_t U_i^W(\mathit{disclose}@t)$ in equation (18) and $\mathrm{E}_t U_i^W(\mathit{disclose}@t + 2)$ in equation (20).

P1. $\mathrm{E}_t U_i^W(\mathit{disclose}@t)$ lies in a bounded space because $\sigma_i(\alpha_i, t)$ and $h(t)$ are bounded and continuous functions, and $H(t) = \sum_k^\infty p^k \,(1-p)\, h(t+k)$ and $H(t, \tau_j)$ (defined in (19)) are bounded sequences.

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

$$\begin{aligned} \lim_{t\to\infty} \mathrm{E}_t U_i^W(\mathit{disclose}@t) &= (1-\theta)\left[1 + \alpha_i - p^{\Delta\tau_j} \alpha_j \lim_{t\to\infty} \pi_t^i\right], \\ \lim_{t\to\infty} \mathrm{E}_t U_i^W(\mathit{disclose}@t + 2) &= (1-\theta)\left[1 + p^2\alpha_i - p^{\Delta\tau_j} \alpha_j \lim_{t\to\infty} \pi_t^i\right], \end{aligned}$$

with $\Delta\tau_j := \tau_j - t > 0$ and $p^{\Delta\tau_j} \alpha_j \lim_{t\to\infty} \pi_t^i < \infty$ as $\pi_t^i \in [0, 1]$.

If $\alpha_i > 0$, because $p < 1$, in the limit the expected payoffs from delaying disclosure one round are *strictly* smaller than the payoffs from disclosing right away,

$$\lim_{t\to\infty} \mathrm{E}_t U_i^W(\mathit{disclose}@t) > \lim_{t\to\infty} \mathrm{E}_t U_i^W(\mathit{disclose}@t + 2). \tag{A.3}$$

From Lemma 1 we know that in $t = t_i^0$ firm i will delay disclosure (if $\alpha_i > 0$) because $\mathrm{E}_{t_i^0} U_i^W(\mathit{disclose}@t_i^0) < \mathrm{E}_{t_i^0} U_i^W(\mathit{disclose}@t_i^0 + 2)$; condition (A.3) implies that in the limit firm i will *not* delay disclosure. By the intermediate value theorem (and if $\mathrm{E}_t U_i^W(\mathit{disclose}@t)$ and $\mathrm{E}_t U_i^W(\mathit{disclose}@t + 2)$ intersect at most once), there exists a finite value of $\hat{t}_i > t_i^0$ such that $\mathrm{E}_t U_i^W(\mathit{disclose}@t + 2) > \mathrm{E}_t U_i^W(\mathit{disclose}@t)$ for all $t_i^0 < t < \hat{t}_i$ and $\mathrm{E}_t U_i^W(\mathit{disclose}@t + 2) \leq \mathrm{E}_t U_i^W(\mathit{disclose}@t)$ for all $t \geq \hat{t}_i$. Setting $\tau_i^* = \hat{t}_i$ establishes the proof.

If $\mathrm{E}_t U_i^W(disclose@t)$ and $\mathrm{E}_t U_i^W(disclose@t+2)$ intersect more than once, there exist multiple finite values of $\hat{t}_i > t_i^0$ such that $\mathrm{E}_t U_i^W(disclose@t+2) > \mathrm{E}_t U_i^W(disclose@t)$ for some $t < \hat{t}_i$ and $\mathrm{E}_t U_i^W(disclose@t+2) \leq \mathrm{E}_t U_i^W(disclose@t)$ for some $t \geq \hat{t}_i$. Then τ_i^* is the smallest of these $\hat{t}_i$. This is because, by Assumption 1, firm i cannot commit to disclose in $t+k$ for any $k \geq 2$. Once delaying disclosure one round is less profitable than disclosing right away, firm i will disclose because delaying disclosure more than one round (so that disclosure in $t+4$ or $t+6$) is not an option. Q.E.D.

Proof of Proposition 5

Proof. By Lemma 1 and Lemma 2. Q.E.D.

Proof of Corollary 1

Proof. By Lemma 5, $\hat{t}_i$ is such that

$$F_i := \mathrm{E}_{\hat{t}_i} U_i^W(disclose@\hat{t}_i) - \mathrm{E}_{\hat{t}_i} U_i^W(disclose@\hat{t}_i + 2) = 0.$$

By the implicit function theorem,

$$\frac{d\hat{t}_i}{dp} = -\left.\frac{\partial F_i}{\partial p}\right/\frac{\partial F_i}{\partial \hat{t}_i} \qquad \text{and} \qquad \frac{d\hat{t}_i}{d\alpha_i} = -\left.\frac{\partial F_i}{\partial \alpha_i}\right/\frac{\partial F_i}{\partial \hat{t}_i}.$$

Claim 1: By definition of $\hat{t}_i$, F_i is increasing in t at $\hat{t}_i$; $\frac{\partial F_i}{\partial \hat{t}_i} > 0$. Moreover,

$$\frac{\partial F_i}{\partial p} = \frac{\mathrm{E}_{\hat{t}_i} U_i(disclose@\hat{t}_i)}{\partial p} - \frac{\mathrm{E}_{\hat{t}_i} U_i(disclose@\hat{t}_i + 2)}{\partial p},$$

with

$$\begin{aligned}\frac{\partial \mathrm{E}_{\hat{t}_i} U_i^W(disclose@\hat{t}_i)}{\partial p} \quad &= \quad (1-\theta)\Bigg[\big(1+\sigma_i(\alpha_i,\hat{t}_i)\big)\sum_{k=0}^{\infty}(1+k)\,p^k\left[h(\hat{t}_i+k+1)-h(\hat{t}_i+k)\right] - \\ &\qquad \frac{\partial}{\partial p}\pi_{\hat{t}_i}^i H(\hat{t}_i,\tau_j)\Bigg] \end{aligned} \tag{A.4}$$

and

$$\begin{aligned}&\frac{\mathrm{E}_{\hat{t}_i} U_i^W(disclose@\hat{t}_i + 2)}{\partial p} = (1-\theta)\Bigg\{\sum_{k=0}^{\infty}(1+k)\,p^k\left[h(\hat{t}_i+k+1)-h(\hat{t}_i+k)\right] + \\ &p^2\sigma_i(\alpha_i,\hat{t}_i+2)\sum_{k=0}^{\infty}(1+k)\,p^k\left[h(\hat{t}_i+k+3)-h(\hat{t}_i+k+2)\right] + 2p\sigma_i(\alpha_i,\hat{t}_i+2)H(\hat{t}_i+2) - \\ &\frac{\partial}{\partial p}\pi_{\hat{t}_i}^i H(\hat{t}_i,\tau_j)\Bigg\}. \end{aligned} \tag{A.5}$$

A sufficient condition for (A.5) to be bigger than (A.4) is that

$$\sum_{k=0}^{\infty}(1+k)\,p^k\left[h(\hat{t}_i+k+3)-h(\hat{t}_i+k+2)\right]+2pH(\hat{t}_i+2)>$$
$$\sum_{k=0}^{\infty}(1+k)\,p^k\left[h(\hat{t}_i+k+1)-h(\hat{t}_i+k)\right], \tag{A.6}$$

which simplifies into

$$h(\hat{t}+1)(1-2p)<h(\hat{t}_i).$$

Therefore, we have that

$$p>{}^1\!/_2\Rightarrow\frac{\partial F_i}{\partial p}<0$$

and

$$p>{}^1\!/_2\Rightarrow\frac{d\hat{t}_i}{dp}=-\left.\frac{\partial F_i}{\partial p}\right/\frac{\partial F_i}{\partial\hat{t}_i}>0.$$

Claim 2: For the effect of α_i on $\hat{t}_i$, we find that

$$\frac{\partial \mathrm{E}_{\hat{t}_i}U_i^W(disclose@\hat{t}_i)}{\partial\alpha_i}=(1-\theta)\left[\frac{\partial\sigma_i(\alpha_i,\hat{t}_i)}{\partial\alpha_i}H(\hat{t}_i)-\frac{\partial}{\partial\alpha_i}\pi^i_{\hat{t}_i}H(\hat{t}_i,\tau_j)\right] \tag{A.7}$$

and

$$\frac{\partial \mathrm{E}_{\hat{t}_i}U_i^W(disclose@\hat{t}_i+2)}{\partial\alpha_i}=(1-\theta)\left[\frac{\partial\sigma_i(\alpha_i,\hat{t}_i+2)}{\partial\alpha_i}p^2H(\hat{t}_i+2)-\frac{\partial}{\partial\alpha_i}\pi^i_{\hat{t}_i}H(\hat{t}_i,\tau_j)\right]. \tag{A.8}$$

Using (A.7) and (A.8),

$$\frac{\partial F_i}{\partial\alpha_i}=(1-\theta)\left[\frac{\partial\sigma_i(\alpha_i,\hat{t}_i)}{\partial\alpha_i}H(\hat{t}_i)-\frac{\partial\sigma_i(\alpha_i,\hat{t}_i+2))}{\partial\alpha_i}p^2H(\hat{t}_i+2)\right].$$

Let $\sigma_i^{\alpha_i}(\alpha_i,t)$ denote the partial derivative of σ_i with respect to α_i. Then

$$\frac{d\hat{t}_i}{d\alpha_i}=-\left.\frac{\partial F_i}{\partial\alpha_i}\right/\frac{\partial F_i}{\partial\hat{t}_i}>0$$

if and only if

$$\sigma_i^{\alpha_i}(\alpha_i,\hat{t}_i)H(\hat{t}_i)<\sigma_i^{\alpha_i}(\alpha_i,\hat{t}_i+2)p^2H(\hat{t}_i+2).$$

Claim 3: It is straightforward to see, by equations (18) and (20), that F_i is not a function of π^i_t or $\sigma_j(\alpha_j,\tau_j)$.
Claim 4: $(1-\theta)$ affects the payoffs in equations (18) and (20) by an equal factor; θ has therefore no effect on $\hat{t}_i$. Q.E.D.

Proof of Lemma 3

Proof. The proof is by

$$\begin{aligned}
\mathrm{E}_2 U_B^W(disclose@4|\tau_A = 1) &= (1-\theta)\left[H(2) + p^2\sigma_B(\alpha_B, 4)H(4)\right] \\
&> (1-\theta)\, H(2) \\
&= \mathrm{E}_2 U_B^W(disclose@2|\tau_A = 1)
\end{aligned}$$

for $\alpha_B > 0$ and $p > 0$, and the arguments presented in the proof of Lemma 1. Q.E.D.

Proof of Lemma 4

Proof. The proof for $\tau_i^*(\tau_j) > \tau_j$ being finite is by the properties of $\mathrm{E}_t U_i^W$ presented in the proof of Lemma 2,

$$\lim_{t\to\infty} \mathrm{E}_t U_i^W(disclose@t|\tau_j) = (1-\theta)\left[1 + \alpha_i - \sigma_j(\alpha_j, \tau_j)\right], \quad \text{(A.9)}$$

$$\lim_{t\to\infty} \mathrm{E}_t U_i^W(disclose@t+2|\tau_j) = (1-\theta)\left[1 + p^2\alpha_i - \sigma_j(\alpha_j, \tau_j)\right], \quad \text{(A.10)}$$

so that

$$\lim_{t\to\infty} \mathrm{E}_t U_i^W(disclose@t|\tau_j) > \lim_{t\to\infty} \mathrm{E}_t U_i^W(disclose@t+2|\tau_j)$$

for $\alpha_i > 0$ because $p < 1$, and by the arguments presented in Lemma 2. Q.E.D.

Proof of Proposition 6

Proof. By Lemma 3 and Lemma 4. Q.E.D.

Proof of Corollary 2

Proof. The proof follows from the observation of $\mathrm{E}_t U_i^W(disclose@t+2) - \mathrm{E}_t U_i^W(disclose@t) = \mathrm{E}_t U_i^W(disclose@t+2|\tau_j) - \mathrm{E}_t U_i^W(disclose@t|\tau_j)$. Q.E.D.

Proof of Lemma 5

Proof. Let i_0 denote a firm i without a patent and i_1 a firm i with a patent. The proof applies to *cases 1* and *2*.

Case 1: Note that $\pi_t^{j*}(\tau_i^*) \in [0,1]$ for all t. We first consider $\tau_i = \tau_i^* = t_i^0 + 4$. The presented arguments can be readily extended to any $\tau_i = \tau_i^* > t_i^0$ and generalized to any $\tau_i = \tau_i' \leq \tau_i^*$. The structure of the proof is such that i moves first, i.e., $i = A$ and $j = B$. This is without loss of generality.

Let $\tau_i^* = t_i^0 + 4$. In $t_j^0 + k$, j's beliefs are denoted by $\pi^j_{t_j^0+k}$, with $k = 0, 2$. We start with the second round (when i moves in $t = t_i^0 + 2$ and j moves in $t = t_j^0 + 2$) and proceeds backward to the first round (when i moves in $t = t_i^0$ and j moves in $t = t_j^0$).

Round 2: In t_j^0+2, by (29) firm j continues if $\pi^j_{t_j^0+2} \leq \pi^{j*}_{t_j^0+2}(t_i^0+4)$ and stops if $\pi^j_{t_j^0+2} > \pi^{j*}_{t_j^0+2}(t_i^0+4)$. A patend holder firm i's decision one stage earlier, in $t = t_i^0+2$, depends on these beliefs $\pi^j_{t_j^0+2}$. If a patent holder i_1 anticipates firm j to continue, i_1 will continue in $t = t_i^0+2$. If, instead, i_1 anticipates j to stop, i_1 will disclose. So, if for $\pi^j_{t_j^0+2} \leq \pi^{j*}_{t_j^0+2}(t_i^0+4)$ firm j in $t = t_j^0+2$ (one stage after i's move) has not observed disclosure, then it is because firm i is either a patent holder (and does not disclose because j will continue) or not a patent holder (and has nothing to disclose, but decides to continue because (33) holds by assumption). This means, firm j does not learn from firm i's behavior firm i's type and cannot update its beliefs. The posterior belief $\pi^j_{t_j^0+2}$ is thus equal to the posterior belief $\pi^j_{t_j^0}$ one round earlier, $\pi^j_{t_j^0+2} = \pi^j_{t_j^0}$. Hence, if $\pi^j_{t_j^0+2} \leq \pi^{j*}_{t_j^0+2}(t_i^0+4)$ then $\pi^j_{t_j^0} \leq \pi^{j*}_{t_j^0+2}(t_i^0+4)$. This implies that firm j continues in $t = t_j^0+2$, and a patent holder firm i_1 continues in $t = t_i^0+2$, so that firm j's beliefs in $t = t_j^0+2$ are $\pi^j_{t_j^0} \leq \pi^{j*}_{t_j^0+2}(t_i^0+4)$. Firm i_1 eventually discloses at $\tau_i^* = t_i^0+4$.

Round 1: If $\pi^j_{t_j^0} \leq \pi^{j*}_{t_j^0}(t_i^0+4)$ so that j continues, then i_1 continues anticipating j to continue. If j in $t = t_j^0$ has not observed disclosure, then the above argument applies: firm j cannot update its beliefs. The posterior belief $\pi^j_{t_j^0}$ is thus equal to the prior belief π^j, $\pi^j_{t_j^0} = \pi^j$. Hence, if $\pi^j_{t_j^0} \leq \pi^{j*}_{t_j^0}(t_i^0+4)$ then $\pi^j \leq \pi^{j*}_{t_j^0}(t_i^0+4)$, and then firm j continues in $t = t_j^0$ and firm i_1 continues in $t = t_i^0$, so that firm j's beliefs in $t = t_j^0$ are $\pi^j \leq \pi^{j*}_{t_j^0}(t_i^0+4)$.

Moreover, if not only $\pi^j \leq \pi^{j*}_{t_j^0}(t_i^0+4)$ (so that i_1 continues in $t = t_i^0$ and j continues in $t = t_j^0$) but also $\pi^j = \pi^j_{t_j^0} \leq \pi^{j*}_{t_j^0+2}(t_i^0+4)$ (so that i_1 continues in $t = t_i^0+2$ and j continues in $t = t_j^0+2$), then both players will continue until $t = t_i^0+4$ when the patent holder i_1 discloses. Hence, if $\pi^j \leq \pi^{j*}_{t_j^0}(t_i^0+4)$ and $\pi^j \leq \pi^{j*}_{t_j^0+2}(t_i^0+4)$ or $\pi^j \leq \min\left\{\pi^{j*}_{t_j^0+k}(t_i^0+4) : k = 0, 2\right\}$, then i_1 discloses in $t = \tau_i^* = t_i^0+4$.

The very same structure applies to $\tau_i^* = t_i^0+6$, $\tau_i^* = t_i^0+8$, and so forth. Hence, if for τ_i^* the prior belief is

$$\pi^j \leq \min\left\{\pi^{j*}_{t_j^0+k}(\tau_i^*) : \forall t_j^0+k < \tau_i^* \text{ with even } k \geq 0\right\}$$

so that j always continues as π^j is always smaller than $\pi^*_{t_j^0+k}(\tau_i^*)$ for all even k, then firm i will disclose in τ_i^*. More generally, if for $\tau_i' \leq \tau_i^*$, the prior belief is

$$\pi^j \leq \min\left\{\pi^{j*}_{t_j^0+k}(\tau_i') : \forall t_j^0+k < \tau_i' \text{ with even } k \geq 0\right\},$$

in Perfect Bayesian Equilibrium (PBE) the firms will continue in all t and firm i discloses in τ_i'.

Case 2 Because (32) is violated for all t, $\pi_t^{j*}(\tau_i^*) > 1 \geq \pi_t^j$ for all t. Because firm j continues if $\pi_t^j \leq \pi_t^{j*}(\tau_i^*)$, it continues for all π_t^j. In PBE firm i continues in all $t_i^0 + k < \tau_i^*$ and firm j continues in all $t_j^0 + k < \tau_i^*$ for any π^j and $k > 0$, and firm i discloses in $t = \tau_i^*$. Q.E.D.

Proof of Lemma 6

Proof. Suppose $\tau_i = \tau_i^*$. Because (31) is violated for all t, $\pi_t^{j*}(\tau_i^*) < 0 \leq \pi_t^j$ for all t. Then because firm j continues if $\pi_t \leq \pi_t^*(\tau_i^*)$, firm j always stops, irrespective of firm i's behavior. Firm i thus chooses to disclose in t_i^0. Q.E.D.

Proof of Lemma 7

Proof. We now study the cases in which (31) and (32) are satisfied for all $t < \tau_i^*$ but (33) is violated for some t in the same range. For simplicity of the argument, we assume that given p, the LHS of (33) is either monotonically non-decreasing in t or monotonically non-increasing in t. Moreover, as in the proof of Lemma 5, let i move first, i.e., $i = A$ and $j = B$. Both assumptions are without loss of generality.

1. Suppose (33) is violated for low t and satisfied for high t. This applies if the LHS in (33) is non-decreasing in t. More specifically, let $t' > t_i^0$ the highest t for which (33) is violated and $t'+1$ the lowest one for which (33) is satisfied. If at $t = t_j^0 = t_i^0 + 1$ firm j has observed continue at $t = t_i^0$, it can infer that firm i is a patent holder, and updates its beliefs so that $\pi_{t_j^0}^j = \pi_{t_j^0+2}^j = \ldots = 1$, implying that firm j continues for all even $t < \tau_i^*$ in which it takes turn. Whether or not (33) is satisfied or violated for higher t is irrelevant. A non-patent holder i_0 has no incentive in prolonging the standardization process and will therefore not mimic a patent holder; firm j anticipates this and correctly infers that it will observe continue only if firm i is a patent holder.

2. Suppose (33) is satisfied for low t and violated for high t. This applies if the LHS in (33) is non-increasing in t. Let t' the highest t for which (33) is satisfied and $t'+1$ the earliest one for which (33) is violated. In this scenario, if firm j has not observed disclosure for all $t \leq t'$, then it is because firm i is i_0 or firm i is firm i_1; that is firm j does not learn from firm i's behavior firm i's type. Therefore, for the conversation to continue until t' the analysis in *case 1* applies, meaning that the process is sustainable if j's prior belief is such that:

$$\pi^j \leq \min\left\{\pi_{t_j^0+k}^{j*}(t') : \forall t_j^0 + k \leq t' \text{ with even } k \geq 0\right\}.$$

   Otherwise, if not such t' exists than disclosure is not delayed. If t' has been reached, from there on two cases must be distinguished, depending on whether $t'+1$ is even or odd.

   - Assume $t'+1$ is odd, so firm i takes turn at $t = t'+1$. If firm j observes that i continues in $t'+1$, then it will update its beliefs so that $\pi_{t'+2}^j = \pi_{t'+4}^j = \ldots = 1$. Thus for all $t \geq t'+2$, *case 2* applies, meaning that disclosure is at $\tilde{\tau}_i = \tau_i^*$.

- Assume that $t' + 1$ is even, so at $t' + 1$ firm j takes turn: Then (33) is satisfied (and a non-patent holder will want to continue) in t' but is violated in $t' + 1$ when j moves. This implies that from i's move, j cannot infer i's type, and in $t' + 1$ will not continue for all π_t^j but only if $\pi_{t'+1}^j \leq \pi_{t'+1}^{j*}(\tau_i^*)$. Up to t', j has not been able to update his beliefs, so that $\pi_{t'+1}^j = \pi^j$. If $\pi^j \leq \pi_{t'+1}^{j*}(\tau_i^*)$, then j continues in $t' + 1$, and i continues in t' anticipating j's continuation. For all $t > t' + 2$, *case 2* applies. If, on the other hand, $\pi^j > \pi_{t'+1}^{j*}(\tau_i^*)$, j stops in $t' + 1$, and i discloses in t'. Q.E.D.