

Patent Disclosure in Standard Setting*

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Abstract

In a model of industry standard setting with private information about firms' intellectual property we analyze (a) firms' incentives to contribute to the development and improvement of a standard, and (b) the firms' decision to disclose the existence of relevant intellectual property to other participants of the standardization process. We find that a firm's incentives to contribute are stronger the stronger is its own intellectual property and the weaker is product market competition. Firms strategically delay disclosure of their intellectual property to other participants, with the propensity to delay stronger in more innovative standardization processes and when the firm's intellectual property is stronger, i.e., the patent more likely to be found valid. We further discuss the implications of product market collusion and the existence of a "lead firm" on firms' incentives and the conditions under which firms will enter a cross-licensing agreement.

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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 as they improve the rate of diffusion of new technologies² and eliminate mis-coordination among producers.³ In this paper, we study how the effectiveness of the process of developing and improving a standard is affected when new technologies are patent-protected. We ask to what extent strategic disclosure of these patents undermines the work of a standard setting organization (SSO).

Conflicting and vested interests can have a significant impact on the process and may arise from problems of asymmetric information or tensions due to fierce product market competition. [Simcoe \(forthcoming\)](#) and [Farrell and Simcoe \(2009\)](#) highlight the impact of strategic interests on the delay of standard adoption.⁴ [Lerner and Tirole \(2006\)](#) analyze the scope for forum shopping among SSOs and, in a related context, [Chiao, Lerner, and Tirole \(2007\)](#) study the relationship between intellectual property disclosure rules and the level of license prices. The argument—a key assumption to this paper’s analysis—is that disclosure of intellectual property may be used strategically as it can provide the patent holder with a bargaining leverage over a patent’s prospective users. This is often referred to as patent holdup or patent ambush.^{5,6}

For the baseline model we assume an institutional setting that implies a *waiver* of intellectual property if patents are not disclosed timely to other participants⁷ and

¹See 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 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).

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

⁴The empirical literature shows that these strategic effects are likely to be amplified if the standard incorporates intellectual property. See [Weiss and Sirbu \(1990:2026\)](#) or [Farrell and Klemperer \(2007\)](#). Also, [Feldman, Graham, and Simcoe \(2009\)](#) document that patents disclosed to SSOs are highly litigated.

⁵See [Farrell, Hayes, Shapiro, and Sullivan \(2007\)](#); [Lemley and Shapiro \(2007\)](#); [Farrell and Shapiro \(2008\)](#); [Ganglmair, Froeb, and Werden \(forthcoming\)](#); [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 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 overrated. 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.

⁶Many of the legal cases regarding SSOs deal with disclosure issues: In the FTC matters against Dell Computer Corp. (*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), 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.

⁷For example, see the European Commission’s press release on the Rambus case (“*Antitrust:*

endogenize the intensity of patent holdup by allowing the patent holder’s bargaining leverage to depend on the timing of disclosure. We find that firms have an incentive to delay disclosure, and that this propensity to delay is increasing in patent strength, i.e., the probability that the patent is indeed valid, and the innovativeness of the standardization process. However, whether or not the firm’s *aspired* disclosure date is observed in equilibrium depends on the other participants’ incentives to contribute. A firm anticipating that other participants prematurely stop the process will find it optimal to disclose the patent earlier than *aspired*, and possibly not delay disclosure at all.

We present a dynamic model with asymmetric information based on [Stein \(2008\)](#)⁸, in which two product-market competitors (each is monopolist in one segment of the market and competes in another) are engaged in the process of standardization. They contribute to the standard by taking turns in suggesting new ideas for standard improvements. The standardization process is said to be more productive as the probability with which such ideas arrive increases. The model is based on three 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., [Stein, 2008](#); [Hellmann and Perotti, forthcoming](#)).⁹

Second, firms potentially own intellectual property on the first idea they communicate. More specifically, we assume that a firm *A* initiates the standardization process by proposing a patent-protected technology. The first idea a firm *B* can communicate is potentially patent-protected. We assume asymmetric information about the existence of intellectual property. This means, firm *B* does not know about firm *A*’s patent but has prior beliefs. Likewise, firm *A* does not know about firm *B*’s patent, but has prior beliefs. [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.”¹⁰ Therefore,

*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 un-enforceability remedy limited in scope to any [standard]-compliant products.”).*

⁸The model in [Hellmann and Perotti \(forthcoming\)](#) shares many features with [Stein \(2008\)](#).

⁹If a firm *B* in $t+1$ does not exchange a new idea, then firm *A* gains no new insights and information. If, then, firm *A* were to find a new idea in $t+2$, it would have already found and communicated the idea in t .

¹⁰The 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. During a public hearing conducted by the Department of Justice and the Federal Trade Commission in 2007, expert panelists reported that “[c]omplying with

unless disclosed by its holder, members of a standard setting organization may at best have a prior belief as to whether or not a given (essential) technology in the standard is patent protected.

Third, the patent holder can demand the payment of license fees from other firms producing within the standard. These license fees depend on and—given a firm’s profits—are strictly increasing in the patent holder’s bargaining leverage as a result of the technology users’ lock-in. Such lock-in arises when firms rely on the standard—yet to be certified and adopted—, make standard-specific investment, and manufacture final products based on the present state of standard proposal.¹¹ We assume that the extent of lock-in increases as the patent holder delays disclosure of its patent.

These model assumptions give to two tradeoffs that drive the model. The first tradeoff is analyzed in [Stein \(2008\)](#)—in a different context—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 communication and does not reveal a new idea for improvement, it gains an advantage over its product-market rival. This latter effect introduces an incentive not to contribute but halt communication during the standardization process.

The second tradeoff concerns firms’ disclosure decision. On the one hand, 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 once no new idea for improvement has arrived.¹²

We derive the results for the model in three steps. First, we provide the conditions for the firm to be willing to continue to contribute to the standardization process once both firms have disclosed intellectual property. This means both firms can extract product-market profits from the other firm by means of license fees. These *post-disclosure* communication incentives for a firm i are stronger the stronger is its intellectual property and the later it has disclosed its patent. Moreover, if firm i would continue the process in a world without intellectual property, then its communication incentives are weaker the stronger another firm j ’s intellectual property (Proposition 2).

Second, given the firms’ behavior *after* disclosure, we study a firm i ’s disclosure decision when it does not worry about firm j ’s communication constraints to be binding. This means, we characterize the firms’ unconstrained or *aspired* date of patent disclosure. We show that firms will always want to delay disclosure, but not perpetually. Even when anticipating that firm j will never stop the process, firm i plans to

different disclosure policies in different SSOs can be costly to intellectual property holders” ([U.S. Dep’t of Justice & Fed. Trade Comm’n, 2007:43](#))

¹¹When 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 producing “pre-N” products for over a year before the final specification of the standard was certified.

¹²We relax the assumption of an implied waiver in the section with model extension. This latter effect does then not arise.

disclose eventually (Propositions 3 and 4). We provide comparative statics for this aspired date of patent disclosure and show that the firms' propensity to delay disclosure is stronger in more productive or more innovative standardization processes (given a minimum level of productivity) and with stronger intellectual property as long as the standardization process is sufficiently productive. We also show that firm j 's intellectual property as well as the degree of product market competition does not affect firm i 's propensity to delay disclosure (Corollaries 1 and 2).

In a final step, we explicitly account for firm j 's communication incentives when we analyze firm i 's decision to disclose. We show when and how firm j 's threat to stop the standardization process affects firm i 's decision. We first derive an upper bound of firm j 's posterior beliefs about firm i having a patent, implying that if the beliefs are higher than this upper bound, firm j will not continue but stop the standardization process. Following this, we present a necessary condition for equilibrium disclosure to be unconstrained, i.e., equal to firm i 's aspired disclosure (Proposition 5), and discuss its comparative statics (Corollary 3). Equilibrium disclosure is constrained and earlier than aspired disclosure with higher product competition, weaker firm j 's intellectual property, and a less productive standardization process.

Our model can be employed to analyze a number of institutions relevant for patent disclosure. First, we relax the assumption of the *implied waiver*, i.e., firms do not lose their bargaining leverage if they disclose after the standardization process has come to an end. In this *no-waiver* regime, firms will always disclose their patents only after the end of the standardization process. Second, we introduce the possibility of cross-licensing agreements which eliminates the strategic aspect of patent disclosure. We show that cross-licensing agreements are desirable when firms are *pessimistic* about the existence of their own intellectual property and thus their chances to gain higher expected profits in a non-cooperative environment with the cross-licensing agreement. Third, we analyze a standard setting environment characterized by the presence of a "lead firm" that either has access to a larger monopoly market than its competitor or initiates the standardization process with a highly developed technology which the receiving firm will expect to be patent protected with very high probability. Both views reduce incentives to communicate, resulting in equilibrium disclosure to be more likely constrained than not. Fourth, we show that product market collusion spurs firms' communication and hence limits the scope for disclosure to be constrained in equilibrium.

To our knowledge our model is the first to endogenize patent holdup in standard setting. Our results further contribute to the literature on knowledge sharing and diffusion (Anton and Yao, 2002, 2004; Haeussler, Jiang, Thursby, and Thursby, 2009; Hellmann and Perotti, forthcoming; Stein, 2008; von Hippel, 1987). von Hippel (1987), in an early contribution, studies the problem of technical know-how trading among technicians of competing firms. By means of case studies, he shows that cooperative communication between competitors can take place; such conversation, however, is

not sustainable when very harsh competition is at work.¹³ We deliver the analogous result that tough competition impedes firms' discussions and prevents cooperative standardization (Proposition 1). With a focus on the complementarity of information,¹⁴ 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 the baseline model. 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 present the equilibrium analysis of patent disclosure. In Section 5 we discuss extensions of the model. We conclude in Section 6. 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.¹⁵ Once the process comes to an end the standard comprises the stock of improving 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 The Standard Setting Process

The firms take turns with A moving at stages $t = 1, 3, 5, \dots$ and B moving at stages $t = 2, 4, 6, \dots$. 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 $T_i := \{t_i^0, t_i^0 + 2, t_i^0 + 4, \dots\}$. At stage $t = 1$, firm A has access to a patent-protected technology χ_1 , and firm B has a prior belief $\pi^B > 0$ 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 A has a prior

¹³von Hippel (1987) makes the example of the aerospace industry, where firms competing for an important government contract report not to trade information with rivals.

¹⁴See also Hellmann and Perotti (forthcoming) or Stein (2008).

¹⁵Firms may have a lot of ideas, yet ideas that actually improve the standard arrive with constant probability.

belief $\pi^A > 0$ that this χ_2 is patent-protected. All future ideas χ_t , $t \geq 3$, are not patent-protected. Beliefs π^B and π^A 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 so 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' pre-commitment as follows:

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

A central assumption about the process of standard setting is the one of strict complementarity of ideas (Stein, 2008; Hellmann and Perotti, forthcoming).

ASSUMPTION 2. *Ideas are strictly complementary. If a new idea does not arrive or one of the firms decides to stop, the standardization process ends.*

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 . Once the process ends, the firms' payoffs are materialized. The structure of the game is depicted in Figure 1.¹⁶

2.2 Payoffs

We use an extended version of the *product market* setting in Stein (2008) and allow firms to collect *license fees* for their intellectual property, if existent.

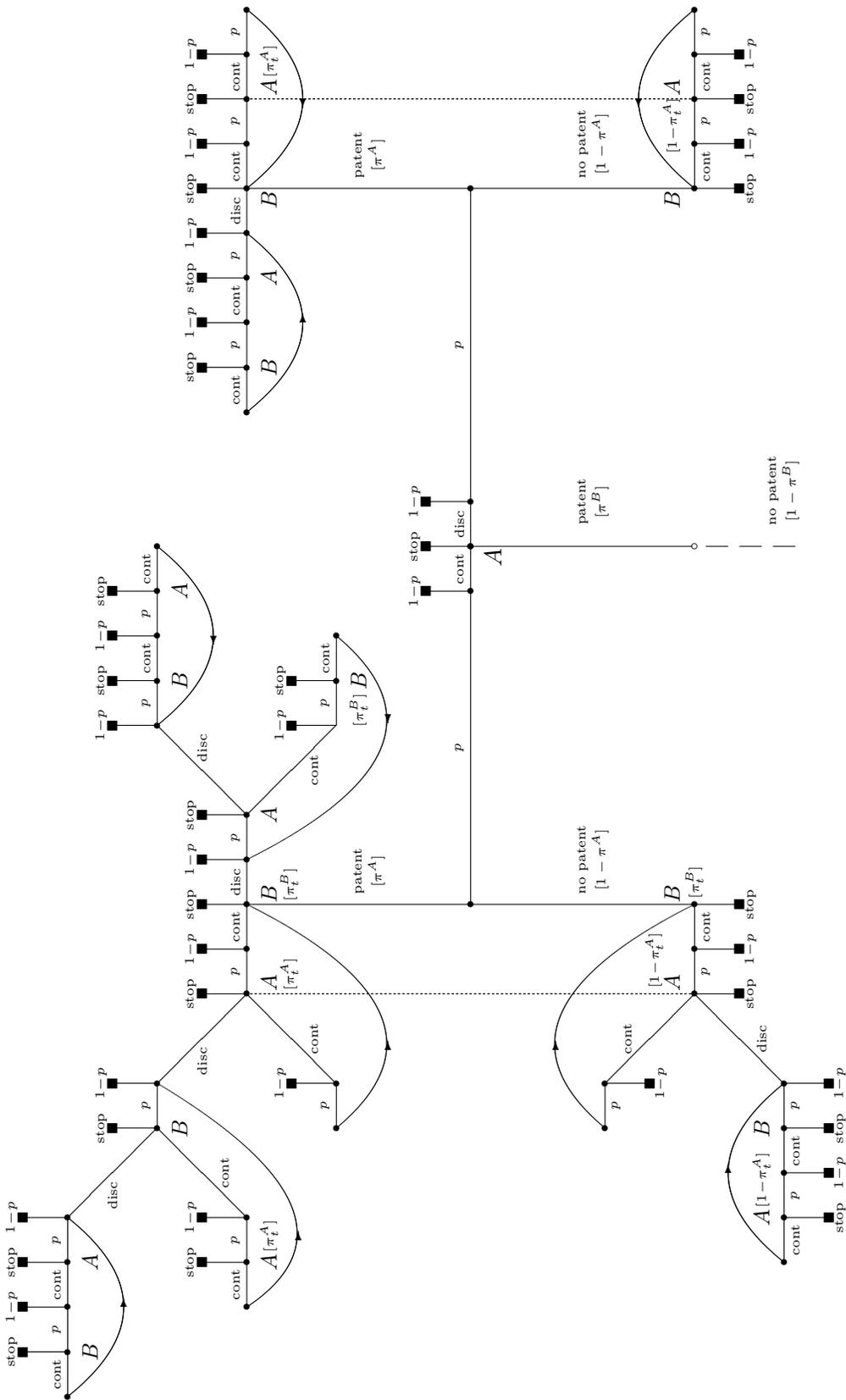
2.2.1 Product Market

We assume that firms A and B each face a market of unit mass. 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 à la Bertrand for the remaining fraction θ .

For our purposes, the product-market effects of the standard are of either one of the following two types. (a) Due to interoperability or network effects, the standard increases the consumers' reservation value of a good that manufacturers are able to produce at constant cost. For simplicity we assume these costs to be equal to zero.

¹⁶Note 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 When Firm A Has a Patent



(b) The standard lowers the costs of production of a good for which consumers have a constant reservation value. We assume this reservation value to be equal to one.

The value of the standard, i.e., the positive effect on the reservation value or the cost savings, increases with the number of ideas of improvement exchanged and thus with the number of rounds of the standard setting process. We denote this number by $n_S \geq 0$. A function $h(n_S)$ captures the reservation-value or cost-saving effect.

ASSUMPTION 3. $h(n_S)$ is increasing and continuous in n_S with $h(0) = 0$ and $\lim_{n_S \rightarrow \infty} h(n_S) = 1$.

We show below that given these assumptions, the product market profits are equal to

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

Suppose the standard is of type (a) and increases the consumers' reservation value of the good. Let $h(n_i)$ denote this reservation value for a product i that is developed on a stock n_i of ideas. A consumer's utility from buying product i at price p_i is equal to

$$u_i(p_i) = h(n_i) - p_i. \quad (2)$$

Assume a firm does not communicate a new idea for standard improvement and stops the process, then both firms produce the good under standard n_S , but the firm that stops the process has an advantage due to an additional unrevealed idea. In other words, if firm i stops the process it markets a product that is developed on a stock $n_i = n_S + 1 > n_j = n_S$ of ideas. Thus, the consumers' reservation value for product i is higher than for product j , $h(n_i) = h(n_S + 1) > h(n_j)$. Alternatively, if the standardization process stops because a new idea does not arrive, $h(n_i) = h(n_S) = h(n_j)$.

In the monopoly-segment of its market, with size $(1 - \theta)$, firm $i = A, B$ sets a price equal to the consumers' reservation value, $p_i = h(n_i)$. In the competitive segment, fraction θ of its unit size market, firm $i = A, B$ sets a price $p_i = \max \{0, h(n_i) - h(n_j)\}$, with $j = A, B$ and $i \neq j$. To see why this is the case, assume $n_i > n_j$. For prices $p_i = p_j = 0$ consumers will buy good i because

$$u_i(0) = h(n_i) - 0 > u_j(0) = h(n_j) - 0$$

and both firms—assuming zero production costs—make zero profits. For firm i , however, $p_i = 0$ is not the Bertrand equilibrium price. Let p_j , then consumers will buy good i if

$$u_i(p_i) = h(n_i) - p_i \geq h(n_j) = u_j(0).$$

The highest price for which this holds true is $p_i = h(n_i) - h(n_j)$. Firm i 's total product market profits are equal to the expression in (1).

Suppose the standard is of type (b) and lowers the firms' costs of production.¹⁷ More specifically, a firm having access to a stock of ideas n_i produces the good at cost $1 - h(n_i)$. If firm i decides not to communicate a new idea, then firm i 's production costs are $1 - h(n_S + 1) < 1 - h(n_S)$. In the monopoly segment of its market, firm i sets a price equal to the consumers' reservation value. Its monopoly profits are then equal to $h(n_i)$. In the competitive segment of its market, firm i makes profits only if its costs are strictly below those of firm j so that it can make a price offer just below firm j 's. This price is (an infinitesimally small amount) below $1 - h(n_j)$ (firm j 's production costs), so that competition profits for firm i are $1 - h(n_j) - (1 - h(n_i)) = h(n_i) - h(n_j)$. Firm i 's total product market profits are equal to the expression in (1).

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 license fee depends on the degree of lock-in of firm j and the resulting bargaining leverage for firm i (i.e., *holdup*). The function $\sigma : (0, 1) \times T_i \rightarrow [0, 1]$ is defined as the fraction of firm j 's product market 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 4 (License Fees).

1. $\sigma(\alpha_i, \tau_i)$ is continuous and increasing in $\alpha_i \in [0, 1]$ and $\tau_i \in T_i$;
2. $\sigma(\alpha_i, \tau_i) > 0$ if and only if $\alpha_i > 0$ and $\tau_i > t_i^0$; $\sigma(0, \tau_i) = \sigma(\alpha_i, t_i^0) = 0$ otherwise;
3. $\lim_{t \rightarrow \infty} \sigma(\alpha_i, t) = \alpha_i < 1$;

The positive effect of α_i on $\sigma(\alpha_i, \tau_i)$ 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 $\sigma(\alpha_i, \tau_i)$ 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.¹⁸

We add the following institutional constraint.¹⁹ We assume the rules of the standard-setting organization to be such that firm must disclose intellectual property before the standardization process comes to an end. In accordance with the legal cases discussed in the introduction, if patents on $\chi_{t_i^0}$ have not been disclosed, i.e., if disclosure is not timely, these are considered to be waived.

¹⁷This is the modeling assumption in Stein (2008).

¹⁸See the discussion of the Belkin case in the introduction.

¹⁹We develop an extension of the model in which we drop this assumption.

ASSUMPTION 5 (Implied Waiver). *If the patent has not been disclosed by the time the standardization process comes to an end, then $\sigma(\alpha_i, \tau_i) = 0$.*

Product market profits R_i in (1) are the firms' overall profits when $\sigma(\alpha_i, \tau_i) = \sigma(\alpha_j, \tau_j) = 0$. 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:

$$U_i(i, j) = (1 - \sigma(\alpha_j, \tau_j)) R_i + \sigma(\alpha_i, \tau_i) R_j; \quad (3)$$

$U_i(i, 0)$ is firm i 's utility when i has timely disclosed and j does not own intellectual property or has not timely disclosed:

$$U_i(i, 0) = R_i + \sigma(\alpha_i, \tau_i) R_j; \quad (4)$$

$U_i(0, j)$ is firm i 's utility when i has not timely disclosed and j has timely disclosed:

$$U_i(0, j) = (1 - \sigma(\alpha_j, \tau_j)) R_i + R_j; \quad (5)$$

finally, $U_i(0, 0) = R_i$.

3 First Best and Cooperative Equilibrium

In a first-best world, both firms communicate respective ideas for standard improvement until a new idea fails to arrive. This maximizes the expected number of ideas, n_S , and thus the value of the standard. Whether or not the firms disclose their intellectual property has no impact on this value as disclosure has no social value. This is because

$$\begin{aligned} U_A(A, B) + U_B(B, A) &= U_A(A, 0) + U_B(0, A) = \\ U_A(0, B) + U_B(B, 0) &= U_A(0, 0) + U_B(0, 0) = R_A + R_B. \end{aligned} \quad (6)$$

Before we analyze the firms' incentives when standardization is non-cooperative, we consider standardization as a cooperative process and ask under what conditions the first-best scenario can be implemented as cooperative equilibrium. In a cooperative equilibrium, firms A and B behave as if they were a single agent, thus they maximize joint profits, $R_A + R_B$, and exchange the information on the existence of relevant intellectual property.

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

$$R_A + R_B = 2(1 - \theta) h(n_S). \quad (7)$$

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

$$R_i + R_j = h(n_i) + (1 - 2\theta) h(n_j). \quad (8)$$

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 Equilibrium Analysis of Patent Disclosure

In this section we present the results of the non-cooperative communication and disclosure game. We first consider the communication when both firms have already disclosed their patents (post-disclosure incentives). We then proceed to the discussion of firms' unconstrained or *aspired* disclosure date. Assuming that after disclosure both firms will continue the process until a new idea fails to arrive, we derive firm i 's date of disclosure when firm j 's communication incentives are always satisfied. In a third step we explicitly account for firm j 's communication incentives, i.e., consider the possibility that firm i does not reach its aspired disclosure date but will, in equilibrium, disclose before then.

4.1 Post-Disclosure Communication

Suppose all patents have been disclosed, i.e., consider $t > \max\{\tau_i, \tau_j\}$. The analysis is analogous to the steps in Stein (2008:2154-5) but for firm i extracting fraction $\sigma(\alpha_i, \tau_i)$ of j 's product market 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 a firm's own intellectual property.

The formal argument goes as follows. 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

$$E_t U_i(\text{continue}@t|\tau_i, \tau_j) = [1 - \sigma(\alpha_j, \tau_j) + \sigma(\alpha_i, \tau_i)] (1 - \theta) H(t) \quad (9)$$

where

$$H(t) = \sum_{k=0}^{\infty} p^k (1 - p) h(t + k) \quad (10)$$

is increasing in p .²⁰ With probability $(1 - p)$, there will be no further ideas after time t , so the standard comprises $n_S = t$ idea with a total value of $h(t)$ for both firms; with probability $p(1 - p)$, there will be exactly one further idea after t , so the standard comprises $t + 1$ ideas with a total 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

$$U_i(\text{stop}@t|\tau_i, \tau_j) = (1 - \sigma(\alpha_j, \tau_j)) [h(t) - \theta h(t - 1)] + \sigma(\alpha_i, \tau_i)(1 - \theta)h(t - 1). \quad (11)$$

This expression reflects the assumption that if firm i keeps idea χ_t to itself it has a product market advantage over j . It allows firm i to earn not only 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 fraction $1 - \sigma(\alpha_j, \tau_j)$ of its profits. In addition, firm i extracts a fraction $\sigma(\alpha_i, \tau_i)$ of j 's profits $(1 - \theta)h(t - 1)$ from j 's monopoly market.

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

$$\left(1 + \frac{\sigma(\alpha_i, \tau_i)}{1 - \sigma(\alpha_j, \tau_j)}\right) \frac{H(t) - h(t - 1)}{h(t) - h(t - 1)} \geq \frac{1}{1 - \theta}. \quad (12)$$

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

$$\frac{H(t) - h(t - 1)}{h(t) - h(t - 1)} \geq \frac{1}{1 - \theta}. \quad (13)$$

To analyze the impact of $\sigma(\alpha_i, \tau_i)$ and $\sigma(\alpha_j, \tau_j)$ on the relative gains from continuing the process versus *stop*, we compute how the difference between (9) and (11) varies with the value $\sigma(\alpha_i, \tau_i)$ and $\sigma(\alpha_j, \tau_j)$. This is what we do to establish the comparative statics results in [Proposition 2](#).

PROPOSITION 2 (Post-Disclosure Communication). *If condition (12) 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 (13) is satisfied.*

²⁰The 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 $p > 0$.

Both firm i 's own intellectual property and the disclosure date positively affect the firm's bargaining leverage. With firm i 's license fee being a fraction—increasing in the bargaining leverage—of firm j 's product-market product, and these profits increasing in the quality of the standard, a stronger bargaining leverage will increase the additional gains from further communication and strengthen firm i 's incentives to further contribute to the standard. The existence of j 's intellectual property inhibits firm i 's communication incentives only if (13) is satisfied. For this latter result, note that as firm i 's additional gains from further communication are smaller the higher firm j 's bargaining leverage and thus the license fee firm i will have to pay, its incentives to continue will be weakened. This, however, hold only if firm i would continue the process in a world without intellectual property, i.e., when (13) holds.

4.2 Unconstrained or Aspired Patent Disclosure

We start with the simplifying assumptions that (i) after disclosure, both firms always continue the conversation (that is, (12) holds true) and (ii) before disclosure by firm i , firm j will always continue and firm i 's disclosure decision is *unconstrained* by j 's behavior.

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 $\sigma(\alpha_i, t)$ of j 's product market profits. Conversely, by not delaying but disclosing in t , firm i foregoes some license fees because $\sigma(\alpha_i, t) < \sigma(\alpha_i, t + 2)$. In what follows, 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 has disclosed (firm i 's decision to disclose after firm j).

4.2.1 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 $t + 2$), $E_t U_i^W(\text{disclose}@t + 2)$, are at least as high as the expected payoffs from disclosure in t , $E_t U_i^W(\text{disclose}@t)$. 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 $E_{t+2} U_i^W(\text{disclose}@t + 4) \geq E_{t+2} U_i^W(\text{disclose}@t + 2)$; 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 (12) is satisfied) are

$$E_t U_i^W(\text{disclose}@t) = (1 - \theta) [H(t) + \sigma(\alpha_i, t)H(t) - \pi_i^i H(t, \tau_j)] \quad (14)$$

where π_t^i are firm i 's posterior beliefs in t that firm j has a patent. 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 $\sigma(\alpha_i, t)$ 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

$$H(t, \tau_j) = p^{\tau_j - t} \sigma(\alpha_j, \tau_j) H(\tau_j) \quad (15)$$

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

$$E_t U_i^W(\text{disclose@}t + 2) = (1 - \theta) [H(t) + p^2 \sigma(\alpha_i, t + 2) H(t + 2) - \pi_t^i H(t, \tau_j)]. \quad (16)$$

The payoffs from *stop* at t are

$$U_i^W(\text{stop@}t) = h(t) - \theta h(t - 1). \quad (17)$$

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

$$E_t U_i^W(\text{disclose@}t + 2) \geq E_t U_i^W(\text{disclose@}t).$$

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 next lemma we show that, 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 when communication incentives are not binding so that the only reason for the standardization process to come to an end is when a new idea fails to arrive.

PROPOSITION 3 (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

$$E_t U_i^W(\text{disclose}@t) < E_t U_i^W(\text{disclose}@t + 2) \quad (18)$$

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 5, 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 is sufficiently large, 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*

$$\frac{\sigma_{\alpha_i}(\alpha_i, \hat{t}_i)}{\sigma_{\alpha_i}(\alpha_i, \hat{t}_i + 2)} \cdot \frac{H(\hat{t}_i)}{H(\hat{t}_i + 2)} < p^2 \quad (19)$$

where $\sigma_{\alpha_i}(\alpha_i, t)$ is the partial derivative of $\sigma(\alpha_i, t)$ 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 $t + 2$.²¹ We show that if the baseline value of p is high enough, the increase in the payoffs from disclosing in $t + 2$ dominates, so 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 (19) implies that if the increase of the license fees in $t + 2$ is sufficiently larger than the increase of the license fees in t , so to offset the costs of time (p^2), higher patent strength results in later disclosure.

The results in Proposition 3 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 (16) must be at least as high as the payoffs from stopping in (17). This is the case if

$$\frac{H(t) - h(t - 1) + p^2 \sigma(\alpha_i, t + 2) H(t + 2) - \pi_t^i H(t, \tau_j)}{h(t) - h(t - 1)} \geq \frac{1}{1 - \theta}. \quad (20)$$

²¹Indeed, 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. This is because the probability $1 - p^2$ of not reaching $t + 2$ is decreasing in p .

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 $\sigma(\alpha_j, \tau_j)H(\tau_j)$) renders the constraint more binding, as can be seen when using the expression for $H(t, \tau_j)$ in (15).²²

4.2.2 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

$$E_t U_i^W(\text{disclose}@t|\tau_j) = (1 - \theta) [H(t) + (\sigma(\alpha_i, t) - \sigma(\alpha_j, \tau_j)) H(t)] \quad (21)$$

$$E_t U_i^W(\text{disclose}@t + 2|\tau_j) = (1 - \theta) [H(t) + p^2 \sigma(\alpha_i, t + 2) H(t + 2) - \sigma(\alpha_j, \tau_j) H(t)] \quad (22)$$

$$U_i^W(\text{stop}@t|\tau_j) = (1 - \sigma(\alpha_j, \tau_j)) [h(t) - \theta h(t - 1)] \quad (23)$$

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

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

$$E_t U_i^W(\text{disclose}@t + 2|\tau_j) \geq E_t U_i^W(\text{disclose}@t|\tau_j).$$

Lemma 3 that shows delayed disclosure is analogous to Lemma 1. Note that—by construction of this case—because firm i discloses only after firm j has disclosed, firm $i = A$ will always delay disclosure by this assumption, $\tau_A \geq 3$. 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 once firm j has disclosed.

PROPOSITION 4 (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*

$$E_t U_i^W(\text{disclose}@t|\tau_j) < E_t U_i^W(\text{disclose}@t + 2|\tau_j) \quad (24)$$

²²Condition (20) can be rewritten for firm j . We discuss in Section 4.3 how this communication restriction on j 's side will affect firm i 's aspired patent disclosure.

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 provided firm i 's constraint in condition (12). The same condition applies to firm j after both firms have disclosed. The incentives for firm j before i discloses are given in equation (20) for firm j instead of i .

4.3 Constrained or Equilibrium Patent Disclosure

The results in Propositions 3 and 4 present firm i 's planned or *aspired* date of disclosure when it expects firm j always to 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 disclosure decision. In this last step 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 . Firm j will continue the standardization process and reveal any new idea as it arrives if

$$\frac{H(t) - h(t-1) + p^2\sigma(\alpha_j, t+2)H(t+2) - \pi_t^j H(t, \tau_i)}{h(t) - h(t-1)} \geq \frac{1}{1-\theta} \quad (25)$$

holds true given anticipated disclosure by firm i at stage τ_i .²³ We denote by π_t^j firm j 's posterior beliefs in period t that firm i has a patent. Let

$$\pi_t^{j*}(\tau_i) = \frac{(1-\theta)[H(t) + p^2\sigma(\alpha_j, t+2)H(t+2)] - [h(t) - \theta h(t-1)]}{(1-\theta)H(t, \tau_i)} \quad (26)$$

be defined such that (25) 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. This threshold is nonnegative, $\pi_t^{j*}(\tau_i) \geq 0$, if

$$\frac{H(t) - h(t-1) + p^2\sigma(\alpha_j, t+2)H(t+2)}{h(t) - h(t-1)} \geq \frac{1}{1-\theta} \quad (27)$$

($\pi_t^{j*}(\tau_i) = 0$ if (27) holds with equality), and $\pi_t^{j*}(\tau_i) \leq 1$ if

$$\frac{H(t) - h(t-1) + p^2\sigma(\alpha_j, t+2)H(t+2) - H(t, \tau_i)}{h(t) - h(t-1)} \leq \frac{1}{1-\theta} \quad (28)$$

²³Condition (25) for firm j is the analogous to condition (20) for firm i .

($\pi_t^{j*}(\tau_i) = 1$ if (28) holds with equality). Moreover, $\pi_t^{j*}(\tau_i) \in (0, 1)$ if both (27) and (28) hold with strict inequality. Conditions (27) and (28) give rise to the three following cases:

Case 1: $\pi_t^{j*}(\tau_i) \in [0, 1]$ when both condition (27) and condition (28) are satisfied. Firm j continues in t if $\pi_t^j \leq \pi_t^{j*}(\tau_i)$ and stops otherwise.

Case 2: $\pi_t^{j*}(\tau_i) > 1$ when condition (27) is satisfied and condition (28) is violated. Firm j continues in t for all $\pi_t^j \in [0, 1]$.

Case 3: $\pi_t^{j*}(\tau_i) < 0$ when condition (27) is violated and condition (28) is satisfied. 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 (20) 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 not to be a patent holder, firm j expects firm i to continue if

$$\frac{H(t) - h(t-1) - \pi_t^i H(t, \tau_j)}{h(t) - h(t-1)} \geq \frac{1}{1-\theta} \quad (29)$$

and condition (29) is more restrictive than (20). This implies that if (29) 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 (29) 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 (12) 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 (12) be satisfied. Moreover, let condition (29) be satisfied for all $t < \tau_i^*$, where τ_i^* is the aspired disclosure date defined in Proposition 3. 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*

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

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 earlier working assumption). 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 $\pi_{t'+1}^j$ are sufficiently low, i.e., below the critical value in (26). 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 (29), 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 (27) is violated for all $t < \tau_i^*$. This implies that (29) is violated, because (29) is more stringent than (27).

LEMMA 6 (Case 3). *Let (12) be satisfied, and let (29) be violated for all $t < \tau_i^*$ where τ_i^* is the aspired disclosure date defined in Proposition 3. 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 (28) is satisfied, but (27) and (29) 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 (27) and (28) are satisfied for all $t < \tau_i^*$, but (29) is violated for *some* $t < \tau_i^*$.

LEMMA 7. *Consider case 1 and let condition (29) be violated for some $t < \tau_i^*$, where τ_i^* is the aspired disclosure date defined in Proposition 3. Two cases can be distinguished:*

- (a) *If there exists an integer $t' \geq t_i^0$ such that (29) is violated for $t \leq t'$ and (29) 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 (29) is satisfied for $t \leq t'$ and (29) is violated for all $t > t'$, and $\pi^j \leq \min \left\{ \pi_{t_j^0+k}^{j*}(t') : \forall t_j^0 + k \leq t' \text{ with even } k \geq 0 \right\}$,*

but $\pi^j > \pi_{t'+1}^{j*}(\tau_i^*)$, then equilibrium disclosure $\tilde{\tau}_i$ is at stage $\tilde{\tau}_i = t'$. Conversely, if $\pi^j \leq \pi_{t'+1}^{j*}(\tau_i^*)$ 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.²⁴ In Lemma 6, although (29) is violated, disclosure is never delayed because (28) is always violated and thus communication is not sustainable. In Lemma 7, (28) is satisfied. So, in the range of values of t in which (29) 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 such that communication can be sustained. The proof of the following propositions follows from Lemmata 5 through 7 and is omitted.

PROPOSITION 5. *Condition (27) is a necessary condition for equilibrium disclosure to be unconstrained in an environment with Bayesian updating. If (27) holds, firm j has incentive to participate in the standardization process even when it expects firm i to be a patent holder.*

Proposition 5 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 3, and unconstrained. In particular, if (27) is not satisfied (as in Lemma 6) disclosure at τ_i^* is unfeasible. However, even if (27) holds, Lemmata 5 and 7 show that disclosure may still not be at τ_i^* , depending on condition (29).

Condition (27) guarantees that the threshold value for j 's beliefs, $\pi_t^{j*}(\tau_i)$, lies within the unit interval, so that $\pi_t^j \geq 0$ exists such that $\pi_t^j \leq \pi_t^{j*}(\tau_i)$ and firm j is willing to sustain the standardization process even in the presence of a patent holder. The following corollary summarizes the effect of the model parameters on condition (27).

COROLLARY 3. *Condition (27) is more likely to be binding and equilibrium disclosure constrained, $\tilde{\tau}_i < \tau_i^*$, with a higher degree of competition, θ , lower strength of firm j 's intellectual property, α_j , and lower productivity of the standardization process, p .*

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 (25) and a non-patent holder i continues if (29). The relevant conditions are therefore qualitatively analogous to (26), (27), and (28), where the candidate for the *aspired* disclosure stage is as defined in Proposition 4 instead of Proposition 3.

²⁴For the case in which (27) holds whereas (28) and (29) are violated the analysis from *case 2* applies, and equilibrium disclosure $\tilde{\tau}_i$ is always at stage τ_i^* .

5 Extensions

In this section, we discuss the following extensions of our baseline model: We (1) drop the assumption of an implied waiver of intellectual property rights when disclosure is not timely (*no-waiver regime*); (2) study the conditions under which firms will enter a cross-licensing agreement before the standardization process begins; (3) assume product markets are asymmetric in size; (4) show how our model captures a standardization process that does not develop a technology/standard from scratch but simply signs on an existing technology; and (5) consider a scenario in which the two firms collude in the product market.

5.1 A No-Waiver Disclosure Regime

In this extension of our baseline model, we relax Assumption 5. That means firms can disclose their patents either before or after the standardization process comes to an end. 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 $\sigma(\alpha_i, t)$. 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 6, firms will always delay disclosure of their patents and disclose once the process has come to an end.

PROPOSITION 6 (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 $\sigma(\alpha_i, \tau_i)$. Continuing communication increases the value of the standard and thus the firms' market profits, whereas fraction $\sigma(\alpha_i, \tau_i)$ is fixed for all $t \geq \tau_i$. Since $\sigma(\alpha_i, \tau_i)$ 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.²⁵

By Proposition 6, *disclose* is strictly dominated by *continue* for both i and j . To determine the condition for which firm i will continue and not stop,

$$E_t U_i^{NW}(\text{continue}@t) \geq U_i^{NW}(\text{stop}@t), \quad (30)$$

suppose *continue* is the equilibrium strategy for both firms. Then by Proposition 6, they will disclose once a new idea fails to arrive and firm i 's expected payoffs, at t , in

²⁵Proposition 6 implies that—given the communication condition in (34) below is satisfied—the expected disclosure date coincides with the expected duration of the standardization process, $E_1 \tau_i = 1 + \sum_{i=0}^{\infty} p^i (1-p)^i = \frac{1}{1-p}$.

the no-waiver regime are

$$E_t U_i^{NW}(\text{continue}@t) = (1 - \theta) \bar{H}(t) \quad (31)$$

with

$$\bar{H}(t) = H(t) + \sum_{k=0}^{\infty} [\sigma(\alpha_i, t+k) - \pi_t^i \sigma(\alpha_j, t+k)] p^k (1-p) h(t+k). \quad (32)$$

Both $\sigma(\alpha_i, t)$ and $\sigma(\alpha_j, t)$ 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 $\sigma(\alpha_i, t)$ from firm j 's profits, and firm i anticipates, at t , that firm j has a patent with π_t^i .

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

$$U_i^{NW}(\text{stop}@t) = (1 - \pi_t^i \sigma(\alpha_j, t)) [h(t) - \theta h(t-1)] + \sigma(\alpha_i, t)(1 - \theta)h(t-1). \quad (33)$$

Firm i always continues and discloses once a new idea fails to arrive if condition (30), rewritten as

$$\frac{\bar{H}(t) - (1 + \sigma(\alpha_i, t) - \pi_t^i \sigma(\alpha_j, t))h(t-1)}{(1 - \pi_t^i \sigma(\alpha_j, t))(h(t) - h(t-1))} \geq \frac{1}{1 - \theta}. \quad (34)$$

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

PROPOSITION 7 (Communication in No-Waiver Regime). *If condition (34) 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*

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

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 $\sigma(\alpha_j, \tau_j)$ triggers a reduction of firm i 's expected payoffs from *continue* in equation (31) that outweighs the decrease of its payoffs from *stop* in equation (33).

5.2 Cross-Licensing

In order to avoid patent holdup, firms often resort to cross-licensing agreements. In the context of our model such an agreement implies that before the standardization process is initiated, at some time $t = 0$ firms commit to license each other any intellectual property they may hold in some extensive technology class (Galasso, 2011).

For our discussion of cross-licensing agreements we assume that communication incentives are satisfied, meaning that neither firm has an incentive to stop the standardization process.²⁶ If a cross-licensing agreement has been concluded, then firms' joint expected surplus is equal to

$$2(1 - \theta) H(1). \quad (35)$$

The expression in (35) results from the sum of the expected profits of A and B in a cooperative environment. To assess whether a cross-licensing agreement is indeed desirable for both firms, we need to compute total expected payoffs in the non-cooperative setting analyzed in the previous sections and compare them to the payoffs in (35). We assume that in equilibrium neither firm has an incentive to stop the standard setting process. This means, firms disclose their intellectual property at time $\tilde{\tau}_i$, for $i = A, B$, and post-disclosure communication incentives are satisfied.

The expected non-cooperative payoffs at period $t = 0$, before the standard setting process is initiated by firm A with the proposal of the first idea χ_1 , are with expectations over firms holding intellectual property and the outcome of the standard setting process. We have denoted by π^A firm A 's prior beliefs that firm B 's technology χ_2 is patent-protected, and by π^B firm B 's prior beliefs that firm A 's technology χ_1 is patent-protected. For the total expected payoffs evaluated at $t = 0$, we introduce two more probabilities: by $\bar{\pi}^A$ we denote firm A 's expectations in $t = 0$ that it will hold a patent on technology χ_1 in $t = 1$; by $\bar{\pi}^B$ we denote firm B 's expectations in $t = 0$ that it will hold a patent on technology χ_2 arriving in $t = 2$. These probabilities reflect firms' uncertainty over the existence of proprietary technology that may contribute to a future standard setting process at the time in which they negotiate a cross-licensing agreement. We will refer to a firm i as *optimistic* if $\delta_i := \bar{\pi}^i - \pi^j > 0$ and its own beliefs are higher than firm j 's beliefs. Likewise, firm i is said to be *pessimistic* if $\delta_i < 0$.

We first consider the scenario with the *waiver regime* (Assumption 5 applies) and then the *no-waiver regime* (Assumption 5 does not apply).

Waiver Regime Firm i 's expected profits are equal to:

$$E_0 U_i^W = (1 - \theta) [1 + \bar{\pi}^i p^{\tilde{\tau}_i} \sigma(\alpha_i, \tilde{\tau}_i) - \pi^i p^{\tilde{\tau}_j} \sigma(\alpha_j, \tilde{\tau}_j)] H(1).$$

²⁶We show in Proposition 1 that this is possible for a sufficiently low degree of product market competition.

Firm j 's expected profits are equal to:

$$E_0 U_j^W = (1 - \theta) [1 + \bar{\pi}^j p^{\tilde{\tau}_j} \sigma(\alpha_j, \tilde{\tau}_j) - \pi^j p^{\tilde{\tau}_i} \sigma(\alpha_i, \tilde{\tau}_i)] H(1).$$

A cross-licensing agreement is desirable if, and only if, the joint expected non-cooperative payoffs are not higher than the cross-licensing joint payoff in (35),

$$E_0 U_i^W + E_0 U_j^W \leq 2(1 - \theta) H(1),$$

or

$$\delta_i p^{\tilde{\tau}_i} \sigma(\alpha_i, \tilde{\tau}_i) + \delta_j p^{\tilde{\tau}_j} \sigma(\alpha_j, \tilde{\tau}_j) \leq 0. \quad (36)$$

Whether or not a cross-licensing agreement is desirable, depends on firms' beliefs. Suppose firm i 's expectations of holding a patent are the same as firm j 's expectations of firm i holding a patent, $\delta_i = 0$, and the same holds true for firm j . Then condition (36) holds with strict equality and firms are indifferent. Now, suppose that both firms are optimistic, so that $\delta_i > 0$ and $\delta_j > 0$. In this case of disagreement, a cross-licensing agreement is not desirable as (36) is violated.

Disagreement, however, is not sufficient for a cross-licensing agreement to be undesirable. Suppose that firms are pessimistic, so that $\delta_i < 0$ and $\delta_j < 0$. In this case, a cross-licensing agreement is desirable as (36) holds with strict inequality. Finally, if one firm is optimistic, and the other firm pessimistic, the result depends on the extent of their disagreement as well as the equilibrium disclosure dates, $\tilde{\tau}_i$, and bargaining leverage $\sigma(\alpha_i, \tilde{\tau}_i)$, for $i = A, B$.

No-Waiver Regime Firm i 's expected profits are equal to:

$$E_0 U_i^{NW} = (1 - \theta) \left[H(1) + \sum_{k=1}^{\infty} [\bar{\pi}^i \sigma(\alpha_i, k) - \pi^i \sigma(\alpha_j, k)] p^{k-1} (1 - p) h(k) \right].$$

Firm j 's expected profits are equal to:

$$E_0 U_j^{NW} = (1 - \theta) \left[H(1) + \sum_{k=1}^{\infty} [\bar{\pi}^j \sigma(\alpha_j, k) - \pi^j \sigma(\alpha_i, k)] p^{k-1} (1 - p) h(k) \right].$$

Hence, a cross-licensing agreement is desirable if, and only if,

$$E_0 U_i^{NW} + E_0 U_j^{NW} \leq 2(1 - \theta) H(1),$$

or

$$\delta_i \sum_{k=1}^{\infty} \sigma(\alpha_i, k) p^{k-1} h(k) + \delta_j \sum_{k=1}^{\infty} \sigma(\alpha_j, k) p^{k-1} h(k) \leq 0. \quad (37)$$

As in the waiver regime, the condition for cross-licensing negotiations to be success-

ful crucially depends on firms' beliefs. More specifically, if both firms are optimistic (pessimistic)—that is, $\delta_i > 0$ ($\delta_i < 0$) and $\delta_j > 0$ ($\delta_j < 0$)—a cross-licensing agreement is undesirable (desirable) as (37) is violated (satisfied). Finally, if one firm is optimistic, and the other firm pessimistic, the result depends on the extent of their disagreement as well as on their bargaining leverage $\sigma(\alpha_i, k)$, for $i = A, B$ and $k \geq 1$.

PROPOSITION 8 (Cross-Licensing Agreements).

1. *When firms are both optimistic ($\delta_i, \delta_j > 0$), a cross-licensing agreement is not desirable because both (36) and (37) are violated.*
2. *When firm i is pessimistic ($\delta_i < 0$) and firm j is optimistic ($\delta_j > 0$), a cross-licensing agreement is more desirable in the waiver regime if, for a given $\tilde{\tau}_i$, $\tilde{\tau}_j \rightarrow t_j^0$ or $\tilde{\tau}_j \rightarrow \infty$ and (36) is satisfied.*
3. *When firm j is pessimistic ($\delta_j < 0$), a cross-licensing agreement is more desirable in the no-waiver regime if, for a given $\tilde{\tau}_i$, $\tilde{\tau}_j \rightarrow t_j^0$ or $\tilde{\tau}_j \rightarrow \infty$ and (37) is satisfied.*

For an intuition of these results, we first need to understand what are the implications of firms' *optimism* on the desirability of cross-licensing. Assume firms are neither optimistic nor pessimistic, $\delta_i = \delta_j = 0$. Their expectations as to what each of them will earn without a cross-licensing agreement are aligned. If post-disclosure incentives are satisfied, and because license payments are merely transfers from one firm to another, aligned expectations imply that both firms expect joint payoffs from the non-cooperative game with ex-post licenses to be equal to the joint payoffs from the cross-license agreement in (35). If a firm i is optimistic, then it expects to receive higher transfers from firm j than firm j expects to pay. If at least one firm is optimistic, and the other firm not pessimistic, the joint expected payoffs from the non-cooperative game are higher than the cross-licensing payoffs in (35), and the cross-licensing agreement is undesirable.

The interesting cases (Claims 2 and 3 in Proposition 8) are where (at least) one firm is pessimistic. In Claim 2, firm j is the optimistic firm. First note that if firm j is optimistic then it always expects to fare better in the no-waiver than in the waiver regime. In the waiver regime, if it expects to disclose early in the process (so that $\tilde{\tau}_j$ is small given $\tilde{\tau}_i$), then its payoffs become relatively small (since $\sigma(\alpha_j, t)$ is increasing in t), so a cross-licensing agreement is again more likely to be concluded in the waiver than in the no-waiver regime. Analogously, if firm j expects to disclose late in the waiver regime (so that $\tilde{\tau}_j$ is large given $\tilde{\tau}_i$), then a cross-licensing agreement is more desirable in the waiver rather than in the no-waiver regime. The reason is that firm j discounts the gains from strategic disclosure by the probability to reach the disclosure date ($p^{\tilde{\tau}_j}$), which tends to zero as $\tilde{\tau}_j$ grows to infinity, and this reduces the profits in the waiver regime.

If firm j is pessimistic the results in Claim 2 are reverted. Indeed, in Claim 3 when firm j expects to disclose relatively late or relatively early in the waiver regime, cross-licensing is more desirable in the no-waiver regime. The reason is that now a pessimistic

firm j expects to gain more from the waiver than from the no-waiver regime: for the same reasons as above, if $\tilde{\tau}_j$ is small or big the waiver regime payoffs become small (or nil, in the limit) so (37) is less binding than (36).

5.3 Product Market Collusion

The product market game in the basic model assumes that firms compete in a market segment of size θ , and the profitability of a deviation from the equilibrium with communication stems from the profit that the deviator can earn additional profits in this market segment. In the following, we study firms' incentive to collude in the product market. Under the collusive agreement, firms fully extract consumers reservation value on θ and decide how to share expected profits $\theta H(t)$.

We assume that firms play trigger strategies of the following sort: at $t = 1$ firm i sets a collusive price on the fraction θ of the market in which it competes with firm j , with $i, j = A, B$ and $i \neq j$. At any time $t > 1$, i sets the collusive price if j has done the same in every period before t . Otherwise, it reverts to the Bertrand-Nash equilibrium price forever.

Two forms of deviation must be considered, so two incentive constraints must be satisfied for collusion to arise at equilibrium. The first incentive constraint imposes that each firm behaves as dictated by the trigger strategies while communicating its new idea for improvement to the competitor. Intuitively, if the cost from deviating is big enough (that is, if the share of $\theta H(t)$ that each gets in the collusive agreement is sufficiently large), collusion is incentive compatible. The second constraint prescribes that, in each period, every firm has incentive to continue the communication under the collusive agreement than to stop the process, where the payoffs from *continue* must take into account the existence of the collusive agreement on θ .

If product market collusion is incentive compatible, the main implication for our results is that communication is easier to sustain at equilibrium—the payoffs from *continue* are larger when firms collude, whereas the payoffs from *stop* stay the same—and constrained disclosure takes place later, *ceteris paribus*. Instead, the aspired disclosure timing does not change at equilibrium, because the condition that determines aspired disclosure's timing (that is, the comparison between the profits from disclosure in t and from disclosure in $t + 2$) does not depend on market size.²⁷

5.4 “Lead Firm” Proposal

In what follows, we analyze two standard setting environments that are characterized by the presence of a “lead firm”. In the first, the “lead firm” has access to a larger monopolistic market than its competitor. In the second, we consider a scenario in which the “lead firm” proposes to the other a technology whose specifications are highly developed.

²⁷To see this, compare (14) and (17).

5.4.1 Market Asymmetry

Assume that firm A is monopolist on a fraction $1 - \theta$ of its market while firm B is monopolist on a segment of size $\bar{\theta} - \theta$, with $\bar{\theta} \in (\theta, 1)$. Firms compete on the remaining fraction θ of their market.

The profits of A are not affected and as defined in equation (1), with $i = A$. Firm B 's product market profits, on the other hand, are now

$$R_B = (\bar{\theta} - \theta) h(n_B) + \theta \max \{0, h(n_B) - h(n_A)\}.$$

With $\bar{\theta} < 1$, these product market profits are smaller than the profits in equation (1) with $i = B$ and $\bar{\theta} = 1$. As a result, firm A 's communication incentives are weaker, and an equilibrium with communication is less likely sustainable. This is because (for both the post-disclosure and pre-disclosure cases in the waiver and the no-waiver regime) the decrease of firm A 's payoffs from *stop* is smaller than the decrease of firm A 's payoffs from *continue*. Given that for the communication process to be sustained both firms' communication incentives must be satisfied, if $\bar{\theta}$ is small enough, the adverse impact on A 's communication constraints can threaten the sustainability of the equilibrium with communication. As for the consequences on the timing of disclosure, if communication incentives are weaker, patent holders' disclosure decision is more likely to be constrained and the aspired timing of disclosure more difficult to reach.

5.4.2 Advanced Technology Proposal

In the basic model, the standard setting process involves two firms that meet to develop a standard from scratch, that is, starting from an initial idea that needs further significant improvements to be marketed. There, we study a dynamic game in which each standard setting participant assigns arbitrary beliefs on the existence of proprietary technologies. In the following, we look at an environment in which one firm (or "lead firm") approaches the standard setting participants with an initial idea that is highly developed.²⁸

Assume that firm A approaches firm B with an initial technology, χ_1 , that is almost complete in its specifications. We ask what are the features of the non-cooperative equilibrium in this framework. We maintain the assumption that each firm i formulates beliefs π^i on the existence of a patent on χ_{t^i} , with $i = A, B$.

Since firm A proposes to B a fairly complete technology in $t = 1$, it is natural to assume that firm B 's beliefs on the existence of a patent on χ_1 are higher than in the main setup of our paper. The consequence is that firm B is less inclined to continue the standardization process than in the main model, *ceteris paribus*. By Lemma 5 and 7, this can lead to earlier (because more constrained) disclosure in $\tilde{\tau}_A$.

²⁸An initiative of this sort has led to the development of the DSL standard, see DeLacey, Herman, Kiron, and Lerner (2006:23ff).

6 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) competing firms' incentives to communicate ideas for improvements of an industry standard and (b) firms' decisions to disclose the existence of intellectual property to other participants of the standardization process.

As for the analysis of the communication process, we show that a firm's incentives to reveal ideas for standard improvement and thus continue the standardization process are spurred by the existence of its own intellectual property. Moreover, if the degree of market competition rises, communication incentives become weaker, thereby threatening the sustainability of the standardization process.

As for the analysis of firms' disclosure decision, we find that, although firms with valid intellectual property want to strategically postpone disclosure, they plan to reveal their patents before the end of the process. The analysis of the propensity to disclose allows us to further qualify these results. First, we find that disclosure is more likely to be delayed in more productive, i.e., innovative, standard setting organizations. Second, the strength of a firm'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). Moreover, we show that these results do hold also when a firm's disclosure decision is constrained by its competitor's communication incentives, provided a necessary condition is satisfied.

Our model can be employed to analyze further institutions relevant for patent disclosure. More specifically, we study whether firms employ cross-licensing agreement to avoid holdup, we analyze a standard setting environment characterized by the presence of a "lead firm", and we show the impact of product market collusion on firms' communication and disclosure incentives.

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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 improvement 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.,

$$EU^C(\text{continue}@t) < U^C(\text{stop}@t) \quad (\text{A.1})$$

for some t . The joint payoffs from continuing are

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

the joint payoffs from stopping are $U^C(\text{stop}@t) = h(t) + (1 - 2\theta)h(t - 1)$. By $h(t) > h(t - 1)$, $U^C(\text{stop}@t) > 0$ for all θ ; $EU^C(\text{continue}@t) = 0$ for $\theta = 1$ and strictly positive otherwise. The critical value $\theta^C(p, h(\cdot))$ (for which $EU^C(\text{continue}@t) = U^C(\text{stop}@t)$) 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 $1/2$. Suppose for a moment that

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

$E\tilde{U}^C(\text{continue}@t) = U^C(\text{stop}@t)$ for $\theta = 1/2$, and the condition in equation (A.1) holds for $\theta > 0.5$. Because $h(t) < h(t + i)$ for all $i > 0$, $EU^C(\text{continue}@t) > E\tilde{U}^C(\text{continue}@t)$ and $\theta^C(p, h(\cdot)) > 1/2$. Q.E.D.

Proof of Proposition 2

Proof. The first part is by Proposition 2 in Stein (2008:2155). To assess the impact of $\sigma(\alpha_i, \tau_i)$ and $\sigma(\alpha_j, \tau_j)$ on communication incentives, rewrite the difference between (9) and (11) as

$$(1 - \sigma(\alpha_j, \tau_j)) [(1 - \theta)H(t) - [h(t) - \theta h(t - 1)]] + \sigma(\alpha_i, \tau_i) (1 - \theta) [H(t) - h(t - 1)]. \quad (\text{A.2})$$

Claim 1: If $\sigma(\alpha_i, \tau_i)$ 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 3) and thus

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

The positive effect of α_i and τ_i on $\sigma(\alpha_i, \tau_i)$ by Assumption 4 establishes the proof of the impact of $\sigma(\alpha_i, \tau_i)$.

Claim 2: If $\sigma(\alpha_j, \tau_j)$ 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 (13), 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

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

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

$$E_{t_i^0} U_i^W(\text{disclose}@t_i^0 + 2) = (1 - \theta) \left[H(t_i^0) + p^2 \sigma(\alpha_i, t_i^0 + 2) H(t_i^0 + 2) - \pi_{t_i^0}^i H(t_i^0, \tau_j) \right].$$

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

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

Q.E.D.

Proof of Lemma 2

Proof. For simplicity and without loss of generality, we assume that $t \in (t_i^0, \infty) \subset \mathbb{R}_+$. Consider the following properties of the expected payoff functions $E_t U_i^W(\text{disclose}@t)$ in equation (14) and $E_t U_i^W(\text{disclose}@t + 2)$ in equation (16).

P1. $E_t U_i^W(\text{disclose}@t)$ lies in a bounded space because $\sigma(\alpha_i, t)$ and $h(t)$ are bounded and continuous functions, and $H(t) = \sum_{k=0}^{\infty} p^k (1 - p) h(t + k)$ and $H(t, \tau_j)$ (defined in (15)) are bounded sequences.

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

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

with $\Delta\tau_j := \tau_j - t > 0$ and $p^{\Delta\tau_j}\alpha_j \lim_{t \rightarrow \infty} \pi_t^i < \infty$ 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,

$$\lim_{t \rightarrow \infty} E_t U_i^W(\text{disclose@}t) > \lim_{t \rightarrow \infty} E_t U_i^W(\text{disclose@}t + 2). \quad (\text{A.3})$$

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

If $E_t U_i^W(\text{disclose@}t)$ and $E_t U_i^W(\text{disclose@}t + 2)$ intersect more than once, there exist multiple finite values of $\hat{t}_i > t_i^0$ such that $E_t U_i^W(\text{disclose@}t + 2) > E_t U_i^W(\text{disclose@}t)$ for some $t < \hat{t}_i$ and $E_t U_i^W(\text{disclose@}t + 2) \leq E_t U_i^W(\text{disclose@}t)$ 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 to disclosure in $t + 4$ or $t + 6$) is not an option. Q.E.D.

Proof of Proposition 3

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

Proof of Corollary 1

Proof. By Lemma 3, \hat{t}_i is such that

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

By the implicit function theorem,

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

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

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

with

$$\frac{\partial E_{\hat{t}_i} U_i^W(\text{disclose@}\hat{t}_i)}{\partial p} = (1 - \theta) \left[(1 + \sigma(\alpha_i, \hat{t}_i)) \sum_{k=0}^{\infty} (1 + k) p^k [h(\hat{t}_i + k + 1) - h(\hat{t}_i + k)] - \frac{\partial}{\partial p} \pi_{\hat{t}_i}^i H(\hat{t}_i, \tau_j) \right] \quad (\text{A.4})$$

and

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

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

$$\begin{aligned} & p^2 \sum_{k=0}^{\infty} (1 + k) p^k [h(\hat{t}_i + k + 3) - h(\hat{t}_i + k + 2)] + 2pH(\hat{t}_i + 2) = \\ & 2ph(\hat{t}_i + 2) + \sum_{k=2}^{\infty} (1 + k) p^k [h(\hat{t}_i + k + 1) - h(\hat{t}_i + k)] > \\ & \sum_{k=0}^{\infty} (1 + k) p^k [h(\hat{t}_i + k + 1) - h(\hat{t}_i + k)], \end{aligned} \quad (\text{A.6})$$

which simplifies into

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

Therefore, we have that

$$p > 1/2 \Rightarrow \frac{\partial F_i}{\partial p} < 0$$

and

$$p > 1/2 \Rightarrow \frac{d\hat{t}_i}{dp} = - \frac{\partial F_i}{\partial p} / \frac{\partial F_i}{\partial \hat{t}_i} > 0.$$

Note that since (A.6) is a sufficient condition, an increase in the productivity of the communication process can delay the timing of disclosure even for some $p < 1/2$.

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

$$\frac{\partial E_{\hat{t}_i} U_i^W(\text{disclose@}\hat{t}_i)}{\partial \alpha_i} = (1 - \theta) \left[\frac{\partial \sigma(\alpha_i, \hat{t}_i)}{\partial \alpha_i} H(\hat{t}_i) - \frac{\partial}{\partial \alpha_i} \pi_{\hat{t}_i}^i H(\hat{t}_i, \tau_j) \right] \quad (\text{A.7})$$

and

$$\frac{\partial E_{\hat{t}_i} U_i^W(\text{disclose@}\hat{t}_i + 2)}{\partial \alpha_i} = (1 - \theta) \left[\frac{\partial \sigma(\alpha_i, \hat{t}_i + 2)}{\partial \alpha_i} p^2 H(\hat{t}_i + 2) - \frac{\partial}{\partial \alpha_i} \pi_{\hat{t}_i}^i H(\hat{t}_i, \tau_j) \right]. \quad (\text{A.8})$$

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

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

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

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

if and only if

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

Claim 3: It is straightforward to see, by equations (14) and (16), that F_i is not a function of $\pi_{\hat{t}_i}^i$ or $\sigma(\alpha_j, \tau_j)$.

Claim 4: $(1 - \theta)$ affects the payoffs in equations (14) and (16) 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

$$\begin{aligned} E_2 U_B^W(\text{disclose@}4 | \tau_A = 1) &= (1 - \theta) [H(2) + p^2 \sigma_B(\alpha_B, 4) H(4)] \\ &> (1 - \theta) H(2) \\ &= E_2 U_B^W(\text{disclose@}2 | \tau_A = 1) \end{aligned}$$

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 $E_t U_i^W$ presented in the proof of Lemma 2,

$$\lim_{t \rightarrow \infty} E_t U_i^W(\text{disclose@}t | \tau_j) = (1 - \theta) [1 + \alpha_i - \sigma(\alpha_j, \tau_j)], \quad (\text{A.9})$$

$$\lim_{t \rightarrow \infty} E_t U_i^W(\text{disclose@}t + 2 | \tau_j) = (1 - \theta) [1 + p^2 \alpha_i - \sigma(\alpha_j, \tau_j)], \quad (\text{A.10})$$

so that

$$\lim_{t \rightarrow \infty} E_t U_i^W(\text{disclose@}t | \tau_j) > \lim_{t \rightarrow \infty} E_t U_i^W(\text{disclose@}t + 2 | \tau_j)$$

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

Proof of Proposition 4

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

Proof of Corollary 2

Proof. The proof follows from the observation of $E_t U_i^W(\text{disclose}@t+2) - E_t U_i^W(\text{disclose}@t) = E_t U_i^W(\text{disclose}@t + 2|\tau_j) - E_t U_i^W(\text{disclose}@t|\tau_j)$. 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 $\pi_{t_j^0+k}^j$, 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 (25) firm j continues if $\pi_{t_j^0+2}^j \leq \pi_{t_j^0+2}^{j*}(t_i^0 + 4)$ and stops if $\pi_{t_j^0+2}^j > \pi_{t_j^0+2}^{j*}(t_i^0 + 4)$. A patent holder firm i 's decision one stage earlier, in $t = t_i^0 + 2$, depends on these beliefs $\pi_{t_j^0+2}^j$. 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 $\pi_{t_j^0+2}^j \leq \pi_{t_j^0+2}^{j*}(t_i^0 + 4)$ 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 (29) 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 $\pi_{t_j^0+2}^j$ is thus equal to the posterior belief $\pi_{t_j^0}^j$ one round earlier, $\pi_{t_j^0+2}^j = \pi_{t_j^0}^j$. Hence, if $\pi_{t_j^0+2}^j \leq \pi_{t_j^0+2}^{j*}(t_i^0 + 4)$ then $\pi_{t_j^0}^j \leq \pi_{t_j^0+2}^{j*}(t_i^0 + 4)$. 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 $\pi_{t_j^0}^j \leq \pi_{t_j^0+2}^{j*}(t_i^0 + 4)$. Firm i_1 eventually discloses at $\tau_i^* = t_i^0 + 4$.

Round 1: If $\pi_{t_j^0}^j \leq \pi_{t_j^0}^{j*}(t_i^0 + 4)$ 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 $\pi_{t_j^0}^j$ is thus equal to the prior belief π^j , $\pi_{t_j^0}^j = \pi^j$. Hence, if $\pi_{t_j^0}^j \leq \pi_{t_j^0}^{j*}(t_i^0 + 4)$ then $\pi^j \leq \pi_{t_j^0}^{j*}(t_i^0 + 4)$, 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 $\pi^j \leq \pi_{t_j^0}^{j*}(t_i^0 + 4)$.

Moreover, if not only $\pi^j \leq \pi_{t_j^0}^{j*}(t_i^0 + 4)$ (so that i_1 continues in $t = t_i^0$ and j continues in $t = t_j^0$) but also $\pi^j = \pi_{t_j^0}^j \leq \pi_{t_j^0+2}^{j*}(t_i^0 + 4)$ (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 $\pi^j \leq \pi_{t_j^0}^{j*}(t_i^0 + 4)$ and $\pi^j \leq \pi_{t_j^0+2}^{j*}(t_i^0 + 4)$ or $\pi^j \leq \min \left\{ \pi_{t_j^0+k}^{j*}(t_i^0 + 4) : k = 0, 2 \right\}$, 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

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

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

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

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

Case 2 Because (28) 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 (27) 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 (27) and (28) are satisfied for all $t < \tau_i^*$ but (29) is violated for some t in the same range. For simplicity of the argument, we assume that given p , the LHS of (29) 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 (29) is violated for low t and satisfied for high t . This applies if the LHS in (29) is non-decreasing in t . More specifically, let $t' > t_i^0$ the highest t for which (29) is violated and $t' + 1$ the lowest one for which (29) 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 $\pi_{t_j^0}^j = \pi_{t_j^0+2}^j = \dots = 1$, implying that firm j continues for

all even $t < \tau_i^*$ in which it takes turn. Whether or not (29) 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.

- Suppose (29) is satisfied for low t and violated for high t . This applies if the LHS in (29) is non-increasing in t . Let t' the highest t for which (29) is satisfied and $t' + 1$ the earliest one for which (29) 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 $\pi_{t'+2}^j = \pi_{t'+4}^j = \dots = 1$. 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 (29) 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.

Proof of Proposition 7

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 (31) and (33) is higher for $\sigma(\alpha_i, t + k) > 0$ than for $\sigma(\alpha_i, t + k) = 0$ if

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

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 $\sigma(\alpha_j, t+k) > 0$ firm i has weaker incentives to continue than for $\sigma(\alpha_j, t+k) = 0$, if

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

establishing the proof. Q.E.D.

Proof of Proposition 8

Proof. The first claim follows from the discussion preceding the proposition. For the proof of the second and third claims, we first rewrite condition (37):

$$\delta_i \Psi_i + \delta_j \Psi_j \leq 0$$

with

$$\Psi_i := \sum_{k=1}^{\infty} p^{k-1} \sigma(\alpha_i, k) h(k)$$

and

$$\Psi_j := \sum_{k=1}^{\infty} p^{k-1} \sigma(\alpha_j, k) h(k).$$

We further rewrite condition (36):

$$\begin{aligned} \delta_i p^{\tilde{\tau}_i} \sigma(\alpha_i, \tilde{\tau}_i) + \delta_j p^{\tilde{\tau}_j} \sigma(\alpha_j, \tilde{\tau}_j) &\leq 0 && \iff \\ \delta_i p^{\tilde{\tau}_i} \sigma(\alpha_i, \tilde{\tau}_i) \sum_{k=1}^{\infty} p^{k-1} h(k) + \delta_j p^{\tilde{\tau}_j} \sigma(\alpha_j, \tilde{\tau}_j) \sum_{k=1}^{\infty} p^{k-1} h(k) &\leq 0 && \iff \\ \delta_i \sum_{k=1}^{\infty} p^{k-1} p^{\tilde{\tau}_i} \sigma(\alpha_i, \tilde{\tau}_i) h(k) + \delta_j \sum_{k=1}^{\infty} p^{k-1} p^{\tilde{\tau}_j} \sigma(\alpha_j, \tilde{\tau}_j) h(k) &\leq 0 && \iff \\ \delta_i \sum_{k=1}^{\infty} p^{k-1} \sigma(\alpha_i, \tilde{\tau}_i) h(k) + \delta_j \sum_{k=1}^{\infty} p^{k-1} p^{\tilde{\tau}_j - \tilde{\tau}_i} \sigma(\alpha_j, \tilde{\tau}_j) h(k) &\leq 0 && \iff \\ & & & \delta_i \Phi_i + \delta_j \Phi_j \leq 0 \end{aligned}$$

with

$$\begin{aligned} \Phi_i &:= \sum_{k=1}^{\infty} p^{k-1} \sigma(\alpha_i, \tilde{\tau}_i) h(k) \phi(\tilde{\tau}_i, k) = \sum_{k=1}^{\infty} p^{k-1} \sigma(\alpha_i, \tilde{\tau}_i) h(k) \frac{\sigma(\alpha_i, k)}{\sigma(\alpha_i, \tilde{\tau}_i)}, \\ \Phi_j &:= \sum_{k=1}^{\infty} p^{k-1} p^{\tilde{\tau}_j - \tilde{\tau}_i} \sigma(\alpha_j, \tilde{\tau}_j) h(k) \phi(\tilde{\tau}_i, k) = \sum_{k=1}^{\infty} p^{k-1} \frac{p^{\tilde{\tau}_j} \sigma(\alpha_j, \tilde{\tau}_j)}{p^{\tilde{\tau}_i} \sigma(\alpha_i, \tilde{\tau}_i)} h(k) \sigma(\alpha_i, k) \end{aligned}$$

and $\phi(\tilde{\tau}_i, k) = \sigma(\alpha_i, k)/\sigma(\alpha_i, \tilde{\tau}_i) > 0$ such that $\Psi_i = \Phi_i$. Observe that for any $\tilde{\tau}_i$, such a $\phi(\tilde{\tau}_i, k) > 0$ exists. If $\Psi_i = \Phi_i$ then $\delta_i \Phi_i = \delta_i \Psi_i$, hence the comparison between $\delta_i \Phi_i + \delta_j \Phi_j$ and $\delta_i \Psi_i + \delta_j \Psi_j$ boils down to a comparison between $\delta_j \Phi_j$ and $\delta_j \Psi_j$. To establish whether cross-licensing is more (or less) desirable under the waiver than under the no-waiver regime, we need to show under which conditions $\delta_j \Phi_j < \delta_j \Psi_j$ (or $\delta_j \Phi_j > \delta_j \Psi_j$).

Note that Ψ_j takes positive values independently from $\tilde{\tau}_i$ and $\tilde{\tau}_j$. Hence, we analyze the relationship between Φ_j and Ψ_j by looking at how Φ_j varies as $\tilde{\tau}_i$ and $\tilde{\tau}_j$ vary. It turns out that

$$\lim_{\tilde{\tau}_j \rightarrow \infty} \Phi_j = \lim_{\tilde{\tau}_j \rightarrow t_j^0} \Phi_j = 0 < \Psi_j.$$

That is, as $\tilde{\tau}_j$ becomes very large or very small, Φ_j decreases below Ψ_j . Two cases must be considered, depending on whether firm j is optimistic ($\delta_j > 0$) or pessimistic ($\delta_j < 0$).

Claim 2 In the case of an optimistic firm j ($\delta_j > 0$) a sufficient condition for $\delta_j \Phi_j < \delta_j \Psi_j$ to hold true is that, for a given $\tilde{\tau}_i$, $\tilde{\tau}_j \rightarrow t_j^0$ or $\tilde{\tau}_j \rightarrow \infty$. In this case, for (36) and (37) to be satisfied it must be that $\delta_i < 0$.

Claim 3 In the case of a pessimistic firm j ($\delta_j < 0$) a sufficient condition for $\delta_j \Phi_j > \delta_j \Psi_j$ to hold true is that, for a given $\tilde{\tau}_i$, $\tilde{\tau}_j \rightarrow t_j^0$ or $\tilde{\tau}_j \rightarrow \infty$. In this case, (36) and (37) hold true if either $\delta_i < 0$ or $\delta_i > 0$ but small. Q.E.D.