Patent Disclosure in Standard Setting*

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Abstract

In this paper we analyze the timing of patent disclosure by a patent holder during the process of industry standard setting. In a non-cooperative model of communication with asymmetric information we endogenize patent holdup to study the effect of patent strength, the productivity of industry standard setting, and competition. We find that late disclosure is more likely in more productive standard setting organizations and in less competitive industries.

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1 Introduction

Industry or product standards are developed and implemented to facilitate the interoperability of products and increase their value to customers.\textsuperscript{1} They also have a social function by improving the rate of diffusion of new technologies\textsuperscript{2} and eliminating miscoordination among producers.\textsuperscript{3} In this paper, we study how the effectiveness of the standardization process is affected when new technologies included in standards are patent-protected. We investigate to what extent the scope for “opportunistic” disclosure of these patents undermines the work of a standard setting organization (SSO), a forum for reaching consensus under competitive and strategic tensions.

Conflicting and vested interests that may arise from problems of asymmetric information or tensions due to fierce product market competition, can have a significant impact on the process. Simcoe (2008) and Farrell and Simcoe (2009) highlight the impact of strategic interests on the delay of standard adoption. These strategic effects are likely to be amplified if the standard incorporates intellectual property.\textsuperscript{4} Feldman, Graham, and Simcoe (2009), for example, document that patents disclosed in SSO are highly litigated, and Baron and Pohlmann (2010) study the effect of patent pools on patent disclosure and find that patent pools result in more patent disclosure, suggesting opportunistic patent filings. In a related context, Chiao, Lerner, and Tirole (2007) analyze the relationship between IP disclosure rules\textsuperscript{5}—a patent holder’s obligation to reveal its IP before a final choice is made—and the level of licensing prices. Such disclosure of IP—especially when delayed—may be used strategically as it can provide

\textsuperscript{1}See, e.g., the discussions of standards and network effects in Scotchmer (2004) or Shapiro and Varian (1998).

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

\textsuperscript{3}See the discussion in Farrell and Klemperer (2007:2026f) and the literature cited therein.

\textsuperscript{4}See Weiss and Sirbu (1990:2026) or Farrell and Klemperer (2007).

the owner of IP with a bargaining leverage over prospective users of IP—often referred to as patent holdup or patent ambush.\textsuperscript{6}

In this paper, we endogenize the magnitude of patent holdup and study how patent strength, the efficiency of the standardization process, and competition affect the strategic use of disclosure of IP. We present a dynamic model with asymmetric information based on Stein (2008),\textsuperscript{7} in which two product-market competitors are engaged in the process of standard setting. They take turns in suggesting new standard components. We make two main assumptions: First, ideas for components are complementary insofar as a firm can find a new standard component only if the other firm has suggested a component in the previous round (e.g., Stein, 2008; Hellmann and Perotti, 2010). Second, the model’s information structure is asymmetric. We assume that the initial standard component is a patent-protected technology and the patent holder must decide when to disclose this information to the firm. 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.”\textsuperscript{8} Therefore, unless disclosed by its holder, members of an SSO may at best have a prior belief as to whether or not technologies in the standard are patent protected.\textsuperscript{9}

Our model design gives rise to the following tradeoff: By disclosing early, the patent

\textsuperscript{6}See Farrell, Hayes, Shapiro, and Sullivan (2007); Lemley and Shapiro (2007); Farrell and Shapiro (2008); Ganglmair, Froeb, and Werden (2010); Shapiro (2010); Tarantino (2011), among others.

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

\textsuperscript{8}The identification of a patent that is relevant to the development of a specific standard imposes significant search costs on the firms participating in an SSO, especially when firms with very large patent portfolios are involved in the discussion. Search costs may turn out to be burdensome even for the patent holders. During a public hearing conducted by the Department of Justice and the Federal Trade Commission in 2007, expert panelists reported that “[c]omplying with different disclosure policies in different SSOs can be costly to IP holders, especially for those with large patent portfolios,” and that “if an SSO’s disclosure policy is too burdensome, IP holders won’t come to the table because of the high cost.” (U.S. Dept of Justice & Fed. Trade Comm’n, 2007:43)

\textsuperscript{9}Kobayashi and Wright (2009) or Shapiro (2010) assume naïve manufacturers who are not aware of the possibility of the technology being patent protected.
holder gains from higher efficiency of the standardization process, but loses part of her bargaining leverage from patent holdup. The first factor refers to the benefits of disclosure of intellectual property. As the patent may contain valuable technical information that provides a deeper understanding of the functioning of a certain technology (Anton and Yao, 2003), disclosure can be fruitfully exploited during the standard setting process. Our model captures this by an increased efficiency of the standard setting process, meaning an increased probability with which a firm finds a new component or technology for the standard and the other firm agrees to its inclusion.

The second factor refers to the costs of patent disclosure. The owner of intellectual property of an essential part of the standard can demand the payment of license fees from other firms producing within the standard. The amount of these fees will depend on the strength of the patent (Farrell and Shapiro, 2008) and manufacturer’s switching costs as a result of lock-in. Such lock-in is the result of firms relying on the standard to be adopted and manufacturing final products based on the present state of the non-adopted standard proposal. The existing literature on the ensuing problem of patent holdup in standard setting has assumed the magnitude of holdup to be

10 The American National Standards Institute in its Patent Policy Guidelines, “encourage[s] the early disclosure and identification of patents that may relate to standards under development, so as to thereby promote greater efficiency in standards development practices” (ANSI, 2011:3)

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

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

13 Remarkably, many of the cases regarding SSOs deal with disclosure issues: In the FTC matters against Dell Computer Corp. (FTC order Dell Computer Corp., FTC Docket NO. C-3658, 121 F.T.C. 616 (1996)) and Rambus Inc., FTC v. Rambus Inc., 522 F.3d 456 (D.C. Cir. 2008), the European Commission against Rambus (“Antitrust: Commission confirms sending a Statement of Objections to Rambus”, MEMO/07/330,
exogenous. To our knowledge our model is the first to endogenize patent holdup in standard setting. This means, given patent strength, bargaining leverage is contingent on when the patented technology is included in the standard: The later the patent is disclosed the more manufacturer’s are locked in and the greater is the threat of being held up in ex-post license negotiations. If, however, the patent holder fails to disclose his IP, the result is a waiver his IP rights and the patent holder loses his bargaining leverage.\footnote{http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/07/330, or Broadcom Corp. v. Qualcomm Inc., 501 F.3d 297 (3d Cir. 2007), accusers contended that patentees failed to comply to the disclosure rule of the SSO where the standardization process took place.}

We derive our results by looking at two environments. First, we consider the case in which the non-patent holder’s incentives to participate in the standardization process do not constrain the patent holder’s disclosure decision, meaning the non-patent holder does not want to stop the standardization process. This allows us to analyze the patent holder’s individually optimal disclosure decision and derive conditions for delayed disclosure. We then proceed to the case in which the non-patent holder’s participation decision is binding in the sense that the patent holder’s optimal disclosure cannot be sustained in equilibrium. Explicitly accounting for the non-patent holder’s incentives to end the standardization process, we give conditions under which the unconstrained results cease to apply.

Our model suggests that a valid patent is a necessary condition for the patent holder to delay disclosure, i.e., not disclose at the beginning of the standard setting process. A

\footnote{\text{For example, see the European Commission’s press release on the Rambus case ("Antitrust: Commission accepts commitments from Rambus lowering memory chip royalty rates", IP/09/1897, http://europa.eu/rapid/pressReleasesAction.do?reference=IP/09/1897) and the United States Court of Appeals for the Federal Circuit decision on Qualcomm Inc. v. Broadcom Corp., Docket Number 07-1545. Nos. 2007-1545, 2008-1162. http://caselaw.findlaw.com/us-federal-circuit/1150919.html ("[W]e agree with the district court that, ‘[a] duty to speak can arise from a group relationship in which the working policy of disclosure of related intellectual property rights (‘IPR’) is treated by the group as a whole as imposing an obligation to disclose information […].’ […] In these circumstances, we conclude that it was within the district court’s authority […] to determine that Qualcomm’s misconduct falls within the doctrine of waiver. […] remand with instructions to enter an unenforceability remedy limited in scope to any [standard]-compliant products.").}}
valid patent is not sufficient, though. The *productivity* of the standardization process, i.e., the success probability of innovation, meaning the probability with which firms find further components to add to the standard, is another key factor. If in the absence of disclosure the standard setting process is relatively productive, the patent holder is willing to forego the gains from a rise in productivity and obtain a higher bargaining leverage instead. A small effect on productivity of the process implies a delay of disclosure.

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

Our results contribute not only to the discussion of strategic patent disclosure and holdup in standard setting, but has implications for the general literature on knowledge sharing and diffusion (Anton and Yao, 2002, 2004; Haeussler, Jiang, Thursby, and Thursby, 2009; Hellmann and Perotti, 2010; Stein, 2008; von Hippel, 1987). von Hippel (1987), for instance, in an early contribution studies the problem of technical know-how trading among technicians of competing firms and shows, by means of case studies, that cooperative communications between competitors can take place, how-
ever, such conversations are not sustainable when very harsh competition is at work.\textsuperscript{15} We deliver the analogous result that tough competition impedes firms’ discussions and prevents collaborative standard setting. With a focus on the complementarity of information\textsuperscript{16} Haeussler, Jiang, Thursby, and Thursby (2009) build a model of knowledge diffusion among academic scientists. Their model shares with ours the feature that complementary information is needed to solve a problem and that such information is exchanged among competing agents. They assume that each agent can quit the information sharing game with its own solution to the problem, whereas we rule this out; a successful standard setting process requires collaboration of all parties involved.

The structure of the paper is as follows: In Section 2 we introduce our extension of the model by Stein (2008). In Section 3 we define the first best outcome and show that in cooperative equilibrium a standard setting process cannot be sustained if competition is too fierce. In Section 4 we analyze the non-cooperative equilibria of our baseline model when the non-patent holder’s communication incentives are not binding. In Section 5 we explicitly model the non-patent holder’s incentives and show how they affect the patent holder’s disclosure decision. We conclude in Section 6. The formal proofs of the results are relegated to the appendix.

2 Basic Model

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

\textsuperscript{15}von Hippel (1987) makes the example of the aerospace industry, where firms competing for an important government contract report not to trade information with rivals.

\textsuperscript{16}See also Hellmann and Perotti (2010) or Stein (2008).
$t \geq 2$, the firm to move has an opportunity to find a propose an additional component for the standard. Firm $A$ is vertically integrated firm, i.e., is both innovator and manufacturer. Firm $B$ is a pure manufacturer that contributes to the standardization process without developing new technologies.

### 2.1 Information Structure

At the initial stage $t = 1$, firm $A$ has access to a patent-protected technology $\chi_1$. Firm $B$ has prior beliefs $\pi > 0$ representing the prior probability of the initial technology $\chi_1$ being protected by a patent.

At stage $t = 1$ and any future odd stage, the patent holder has three options: She can (1) stop the process (stay quiet and reveal neither the technology nor the patent), (2) disclose (reveal both the technology and the fact that it is patent-protected), or (3) continue the process (communicate the technology to $B$ but keep the fact that it is patent-protected to herself).\(^{17}\) These actions imply the following for the structure of the standard setting process.

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

2. If $A$ discloses at any odd $t$, meaning revealing the existence of the patent on technology $\chi_1$ and communicating the new technology $\chi_t$, firm $B$ will with probability $q$ develop a new technology and standard component $\chi_{t+1}$ at $t + 1$. If $B$ fails, with probability $1 - q$, the game stops. If successful, firm $B$ can either continue by truthfully revealing technology $\chi_{t+1}$, after which it is $A$'s turn in

\(^{17}\)Note that $A$ can choose not to disclose the patent at $t = 1$ but reconsider her decision at $t = 3, 5, \ldots$
Figure 1: Conversation Game with Patent Disclosure

$t = 1$ (firm $A$)

$t = 2, 4, 6, \ldots$ (firm $B$)

$t = 3, 5, 7, \ldots$ (firm $A$)

$t + 2$; or stop. At $t + 2$, firm $A$ will have disclosed and is left with the decision to either stop or continue.

3. If $A$ continues at any odd $t$ and has disclosed at an earlier stage, the game continues as described above. If $A$ has not yet disclosed the patent and at $t$ decides to continue and therefore keep its existence to herself, firm $B$ develops a new technology and standard component $\chi_{t+1}$ with probability $p < q$.

The structure of the game is depicted in Figure 1. The process continues until one firm fails to produce a new component or decides to stop. Once the process stops, payoffs are realized.
2.2 Payoffs

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

**Product market competition:** The higher the number of components, \( n_S \), and the higher the quality of the standard, the lower the costs the parties incur in production. More specifically, having access to an \( n_S \)-standard, the parties can manufacture the product at cost \((1 - h(n_S))\). Here, \( h(n_S) \) is an increasing function, with \( h(0) = 0 \) and \( \lim_{n_S \to \infty} h(n_S) = 1 \), that captures the total cost savings associated with \( n_S \) components. Also, a party that develops a new technology but decides not to communicate it manufactures the product at cost \((1 - h(n_S + 1)) < (1 - h(n_S))\) and has therefore a cost advantage over its rival.

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

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

**Holdup:** The holdup problem of manufacturers who employ patent-protected technologies is characterized as follows: If patent-holder firm $A$ does not sell a license for the initial patent-protected technology, $\chi_1$, then manufacturer $B$ infringes if selling his products. This threat gives firm $A$ a bargaining leverage that maps into the license fee the parties will negotiate once the standard has been adopted and production commences.

Let $\sigma \in (0, 1)$ be the fraction of $B$’s profits firm $A$ can extract by means of license fees. It depends on two factors: (1) Let $\tau \geq 1$ the timing of disclosure. As more and more components $\chi_t$ are added to the standard, the initial technology $\chi_1$, upon which the standard is built, the degree of lock-in increases. (2) Let $\alpha > 0$ denote the strength of the patent. Suppose no adequate substitute can be found for the patented technology, then firm $A$’s bargaining leverage will eventually depend on how weak or strong the patent is (Farrell and Shapiro, 2008). We assume that $\sigma = \sigma(\alpha, \tau)$ is continuous and increasing in $\alpha$ and $\tau$ with $\sigma(0, \tau) = 0$, $\sigma(\alpha, 1) = 0$ and $\lim_{\tau \to \infty} \sigma(\alpha, \tau) = \alpha$. Moreover, we assume that if firm $A$ fails to disclose the patent before the standard is adopted, i.e., before the standardization process stops, she loses her intellectual property rights and $\sigma = 0$.

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

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

for firm \( A \) and

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

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

3 First Best and Cooperative Equilibrium

In a first-best world, firm \( A \) discloses her patent at \( t = 1 \) and both \( A \) and \( B \) communi-
cate their respective ideas for standard components until they fail to find further ideas.
The intuition for this is straightforward. As more components increase the quality of
the standard and lower the costs of production, communication is socially desirable.
Disclosure of the patent increases the productivity of this process.
A first question is whether the first-best outcome can be implemented in a cooperative equilibrium. The parties’ joint payoffs are

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

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

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

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

$$\frac{1 + \beta q}{2} < \theta. \quad (4)$$

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

The analysis of non-cooperative equilibria demonstrates how patent disclosure and the scope for holdup affect the firms’ incentives to communicate in a standard setting process. We proceed as follows: We first shed light on their incentives to continue communication after the patent has been disclosed\(^{18}\) and then derive conditions for firm A to disclose her patent when firm B’s communication incentives are not binding.

4.1 Post-Disclosure Communication

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

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

\[
E_t U_B(continue @ t | \tau) = (1 - \sigma(\alpha, \tau)) (1 - \theta) H(t | q)
\]

where

\[
H(t | q) = \sum_{i=0}^{\infty} q^i (1 - q) h(t + i).
\]

This expression is increasing in probability \(q\).\(^{19}\) The intuition behind (5) is as follows:

With probability \((1 - q)\), there will be no further ideas after time \(t\), so the standard has \(t\) components with a total cost-cutting value of \(h(t)\) for both parties; with probability \(q (1 - q)\), there will be exactly one further idea after \(t\), so the standard has \(t + 1\)

\(^{18}\)This is analogous to the steps in Stein (2008) but for probability \(q > p\) and sharing rule \(\sigma(\alpha, \tau)\) of B’s profits.

\(^{19}\)More generally, \(H(t|x)\) is increasing in \(x\). The derivative of \(H(t|x)\) with respect to \(x\) is equal to \(\sum_{i=0}^{\infty} x^i \left( \frac{h(1-x)}{2} - 1 \right) h(t + i)\), which, after some manipulation, can be rewritten as \(\sum_{i=0}^{\infty} ix^{i-1}(h(t + i + 1) - h(t + i)) > 0\).
components with a total cost-cutting value of \( h(t+1) \); with probability \( q^2 (1-q) \) there are exactly two further components, and so forth. By contrast, suppose that firm B considers deviating from the equilibrium strategy, i.e., stop at stage \( t \). His payoffs in this case are equal to

\[
U_B(\text{stop}@t|\tau) = (1 - \sigma(\alpha, \tau)) [h(t) - \theta h(t - 1)].
\]

This expression reflects the fact that if B stops, he keeps idea \( \chi_t \) to himself and has therefore a production cost advantage over A. This allows him to not only earn a profit of \( (1 - \theta) h(t) \) in the monopoly market, but also a profit of \( \theta [h(t) - h(t - 1)] \) in the competitive market, in which he underbids firm A by offering a price \( 1 - h(t - 1) \) equal to firm A’s production costs. Because of A’s patent holdup, firm B keeps only a fraction \( (1 - \sigma(\alpha, \tau)) \) of his profits.

For firm B to continue the conversation, \( E_t U_B(\text{continue}@t|\tau) \geq U_B(\text{stop}@t|\tau) \) must hold for all values of \( t > \tau \). This condition is satisfied if and only if

\[
\frac{H(t|q) - h(t - 1)}{h(t) - h(t - 1)} \geq \frac{1}{1 - \theta}.
\] (6)

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

\[
E_t U_A(\text{continue}@t|\tau) = (1 - \theta) (1 + \sigma(\alpha, \tau)) H(t|q).
\] (7)

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

\[ U_A(\text{stop} @ t | \tau) = h(t) - \theta h(t-1) + (1 - \theta) \sigma(\alpha, \tau) h(t-1). \] (8)

It reflects her monopoly and competition profits as well as her share from B’s monopoly market profits. For firm A to always continue the process, \( E_t U_A(\text{continue} @ t | \tau) \geq U_A(\text{stop} @ t | \tau) \) must hold for all values of \( t > \tau \). This is satisfied if and only if

\[ (1 + \sigma(\alpha, \tau)) \frac{H(t|q) - h(t-1)}{h(t) - h(t-1)} \geq \frac{1}{1 - \theta}. \] (9)

We can conclude from conditions (6) and (9) that, after disclosure, if \( \sigma > 0 \), firm A’s incentives to continue the standardization process are stronger than firm B’s. Her condition to continue is therefore never binding.

Continuing the conversation allows A to gain twice from increased productivity, directly and indirectly. A longer communication leads to a better standard and lower production costs for both firms. This has a direct positive impact on A’s profits. The indirect effect arises from the fact that A extracts part of B’s profits by means of license fees. Accordingly, we find that after disclosure A is more eager to continue the communication than B.

The analysis of the firms’ post-disclosure incentives shows that whether or not continuing the standard setting process can be sustained in equilibrium does not depend on the threat of patent holdup as firm B’s continuation decision (6) is independent of \( \sigma \).

4.2 Pre-Disclosure Communication and Patent Disclosure

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

Let firm B’s prior belief of the initial technology \( \chi_1 \) being patent-protected be denoted by \( \pi > 0 \). The beliefs are common knowledge. For the main results we assume that both equations (6) and (9) are satisfied, meaning that once firm A has disclosed the patent, both firms will continue.

**Payoffs Firm A:** At every odd stage \( t \), firm A has to decide whether to *disclose* right away, so that \( \tau = t \), and realize expected payoffs

\[
E_t U_A(\text{disclose} @ t) = (1 - \theta)(1 + \sigma(\alpha, t)) H(t|q),
\]

or postpone disclosure, meaning *continue* at \( t \) and *disclose* at \( t + 2 \) with expected payoffs

\[
E_t U_A(\text{disclose} @ t + 2) = (1 - \theta) \left[ (1 - p) h(t) + p (1 - p) h(t + 1) \right] + (1 - \theta) p^2 (1 + \sigma(\alpha, t + 2)) H(t + 2|q).
\]

Before disclosure, firm A’s payoffs from disclosing at \( t \) in (10) are at least as high as the payoffs from stopping, \( U_A(\text{stop} @ t) = h(t) - \theta h(t - 1) \), if

\[
\frac{(1 + \sigma(\alpha, \tau)) H(t|q) - h(t - 1)}{h(t) - h(t - 1)} \geq \frac{1}{1 - \theta}
\]

which holds by equation (9). This implies that for firm A, stopping is dominated, and the reduced choice set for firm A is either continue or disclose.

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

**Payoffs Firm \(B\):** At every even stage \(t\), firm \(B\) will form beliefs \(\pi_t\) as to the type of firm \(A\). We will refer to a firm \(A\) without a patent as \(A_0\), and a patent holder as \(A_1\). Firm \(B\) anticipates that a non-patent holder \(A_0\) will continue if

\[
\frac{H(t|p) - h(t - 1)}{h(t) - h(t - 1)} \geq \frac{1}{1 - \theta} \quad (13)
\]

holds, with \(H(t|p)\) given as in equation (5) for probability \(p\) instead of \(q\). Because \(q > p\), for a given \(t\), \(H(t|q) > H(t|p)\), so that, for \(q \geq p\) and \(\alpha \geq 0\), condition (13) implies condition (6), and condition (6) implies condition (9).

Moreover, firm \(B\) anticipates that a patent holder \(A_1\) does not stop. As for firm \(B\)'s communication incentives, we introduce the following notation: His payoffs at \(t\) from stopping are

\[
\tilde{U}_B(\text{stop} @ t) = h(t) - \theta h(t - 1). \quad (14)
\]

His expected payoffs at \(t\) from continuing are

\[
E_q \tilde{U}_B(\text{continue} @ t) = (1 - \theta) \left[ H(t|p) + \pi_t \left[ \tilde{H}(t, \tau) - H(t|p) \right] \right]. \quad (15)
\]

Expression \(H(t|p)\) denotes his expected payoffs at \(t\) when he anticipates \(A_0\) (\(\pi_t = 0\)
defined in equation (5) for $q = p$ and

$$\tilde{H}(t, \tau) = \sum_{i=0}^{\tau-t-1} p^i (1 - p) h(t + i) + p^{\tau-t} (1 - \sigma(\alpha, \tau)) H(\tau|q)$$  \hspace{1cm} (16)

denotes his expected payoffs when he anticipates a patent holder $A_1 (\pi_t = 1)$ and disclosure at stage $t = \tau$. At $t$, firm $B$ will choose to continue if and only if (15) ≥ (14), or

$$\frac{H(t|p) - h(t - 1) + \pi_t \left[ \tilde{H}(t, \tau) - H(t|p) \right]}{h(t) - h(t - 1)} \geq \frac{1}{1 - \theta}. \hspace{1cm} (17)$$

For the results in this section we assume that firm $B$’s continuation condition or participation constraint (17) is not binding. This implies that firm $A$ can make her patent disclosure decision without fearing firm $B$ deliberately stopping the standardization process. We can thus consider firm $A$’s decision given firm $B$ continues in all even $t$.

Provided a regularity condition, discussed below, in Proposition 2 we provide a simple necessary and sufficient condition for firm $A$ to delay disclosure to a later period, so that $\tau^* > 1$. We also show that firm $A$ will eventually want to disclose the patent—$\tau^*$ is finite—meaning that unless the process is terminated due to either firm’s failure to find a new component, the patent will always be disclosed.

**PROPOSITION 2** (Unconstrained Disclosure).

Let $E_t U_A(disclose@t)$ and $E_t U_A(disclose@t + 2)$ intersect at most once. If

$$E_1 U_A(disclose@3) \geq E_1 U_A(disclose@1) \hspace{1cm} (18)$$

then firm $A$ delays disclosure. There exists a finite disclosure date $\tau^* > 1$. If (18) does not hold, the patent is disclosed at the outset of the standardization process and $\tau^* = 1$. 
The simple condition in (18) states that if at $t=1$ firm A’s expected payoffs from postponing disclosure one round to $t=3$ are at least as high as from disclosing right away, then disclosure will be delayed at least one round. We reformulate firm A’s disclosure problem as an optimal stopping problem and, using results provided by Stokey and Lucas (1989), we show that a stopping rule exists. Such a case is depicted in panel (a) of Figure 2. We plot the graphs for expected payoffs at $t$ from disclosure at $t$ and disclosure at $t+2$ over time.

[FIGURE 2 ABOUT HERE]

Condition (18) above is a sufficient condition for delayed disclosure. Consider panels (b) and (c) of Figure 2 when the condition is violated. Because in the limit the expected payoffs from delaying are strictly smaller than from disclosing, the two graphs for expected payoffs (disclosure at $t$ and disclosure at $t+2$) never intersect or intersect twice. In the former case, the simple condition is not only sufficient for delayed disclosure but also necessary, because if it does not hold firm A will disclose right away as her expected payoffs will always be strictly higher than the expected payoffs from delaying. In the latter case, we cannot rule out that, although disclosing right away is the dominant action at $t=1$, firm A waits until a point when delaying is dominant (as the graph for disclosure at $t+2$ lies above the graph for disclosure at $t$). We rule out this case by assumption of a regularity condition.

In the following two propositions, we refine the existence result of an optimal stopping rule. We provide the formal proofs in the appendix. In Proposition 3 we show that the presence of valid intellectual property and ensuing threat of patent holdup is a necessary condition for the delay of disclosure. This seems tautological. Without intellectual property there is no intellectual property to disclose. The crucial point is

20\footnote{The two graphs could be tangents or intersect more than twice. For the argument, cases are of no relevance.}
that intellectual property is valid in the sense that (i) it can be enforced, meaning that it is not invalidated by means of an SSO’s IP rules or antitrust agencies’ intervention, and (ii) it is “strong” enough. Without the prospect of a bargaining leverage arising from IP, firm A has no incentive to jeopardize the productivity of the standard setting process by not revealing.

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

The presence of valid intellectual property is a necessary condition for delayed disclosure. However, it is not sufficient. We show in Proposition 4 that, given $\alpha > 0$, there is a lower bound $\bar{p} < q$ for the pre-disclosure success probability $p$ (a measure for the pre-disclosure productivity of the standard setting process) such that condition (18) holds and disclosure is delayed for all $p \geq \bar{p}$; and (18) is violated for all $p < \bar{p}$ so that $\tau = 1$.

**PROPOSITION 4.** Let $\alpha > 0$ and $q > 0$. If the pre-disclosure success probability $p$ is not too low, i.e., for $\bar{p} \leq p < q$ with $\bar{p} > 0$, condition (18) holds and disclosure of the patent is delayed.
If the baseline probability to continue the conversation \((p)\) is relatively high, then the cost of delaying disclosure is small: Firm \(A\) exploits the sufficiently high productivity of the communication to postpone patent’s revelation until the marginal gains from holdup are exhausted.

For the remainder of this section we assume that the pre-disclosure success probability is sufficiently high so that the patent is delayed, \(p \geq \overline{p}\) and \(\tau^* > 1\). By Proposition 2, the disclosure stage \(\tau^*\) is such that the expected payoffs from disclosure in \(t\) in equation (10) are at least as high as the expected payoffs from disclosure in \(t + 2\) in equation (11) for all \(t \geq \tau^*\) and strictly smaller for all \(t < \tau^*\). In Proposition 5 we provide comparative statics for firm \(A\)’s propensity to delay disclosure.

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

\[
\frac{\sigma_\alpha(\alpha, \hat{t})H(\hat{t}|q)}{\sigma_\alpha(\alpha, \hat{t} + 2)H(\hat{t} + 2|q)} < p^2,
\]

then patent strength \(\alpha\) has a delaying effect on patent disclosure.

In Proposition 3 we showed that the existence of enforceable IP is a necessary condition for delay of disclosure, so that \(\tau^* > 1\) and the patent holdup problem arises; in Proposition 4 we provided a sufficient condition for delayed disclosure. Whether or not these two factors of the standard setting process—patent strength \(\alpha\) and the pre-disclosure productivity of the process, \(p\)—have a positive effect on the patent holder’s propensity to delay disclosure, is discussed in Proposition 5.
As in Proposition 4, in Proposition 5 the effect of an increase in \( p \) on the propensity to delay disclosure is clear. However, the impact of patent strength is ambiguous and will eventually depend on the bargaining technology determining the shape of \( \sigma \). A stronger patent increases both the gains from disclosing today and the ones from later disclosure, which are discounted by \( p^2 \). If the latter are sufficiently large, so to offset the cost of time, then patent strength delays disclosure.

5 Patent Disclosure and Firm B’s Communication Incentives

We now turn to firm B’s incentives to participate in the standardization process. Firm B will choose to participate and continue the standardization process if equation (17) holds. Given an anticipated disclosure stage \( \tau \), let

\[
\pi_t^*(\tau) = -\frac{(1 - \theta) H(t|p) - [h(t) - \theta h(t - 1)]}{(1 - \theta) \left( \tilde{H}(t, \tau) - H(t|p) \right)}
\]  

be defined such that (17) holds with strict equality if \( \pi_t = \pi_t^*(\tau) \). This critical value is equal to zero if

\[
\frac{H(t|p) - h(t - 1)}{h(t) - h(t - 1)} \leq \frac{1}{1 - \theta}
\]  

holds with strict equality and equal to unity if

\[
\frac{\tilde{H}(t, \tau) - h(t - 1)}{h(t) - h(t - 1)} \geq \frac{1}{1 - \theta}
\]
holds with strict equality. Moreover, let for some \( \tau \), \( \tilde{H}(t, \tau) > H(t|p) \), then \( \pi^*_i(\tau) \in (0, 1) \) if

\[
\frac{H(t|p) - h(t - 1)}{h(t) - h(t - 1)} < \frac{1}{1 - \theta} \leq \frac{\tilde{H}(t, \tau) - h(t - 1)}{h(t) - h(t - 1)}
\]

and both (21) and (22) hold with strict inequality. Conversely, let for some \( \tau \), \( \tilde{H}(t, \tau) < H(t|p) \), then \( \pi^*_i(\tau) \in (0, 1) \) if

\[
\frac{\tilde{H}(t, \tau) - h(t - 1)}{h(t) - h(t - 1)} \leq \frac{1}{1 - \theta} < \frac{H(t|p) - h(t - 1)}{h(t) - h(t - 1)}
\]

and both (21) and (22) are violated.

**REMARK 1.** Conditions (21) and (22) give rise to six cases:

1.1 Let \( \tilde{H}(t, \tau) > H(t|p) \) so that \( \pi^*_i(\tau) \in [0, 1] \) and firm B continues if \( \pi_t \geq \pi^*_i(\tau) \); stops otherwise. Moreover, both (21) and (22) are satisfied.

1.2 Let \( \tilde{H}(t, \tau) > H(t|p) \) so that \( \pi^*_i(\tau) \in [0, 1] \) and firm B continues if \( \pi_t \geq \pi^*_i(\tau) \); stops otherwise. Moreover, (21) holds and (22) is violated.

1.3 Let \( \tilde{H}(t, \tau) > H(t|p) \) so that \( \pi^*_i(\tau) \in [0, 1] \) and firm B continues if \( \pi_t \geq \pi^*_i(\tau) \); stops otherwise. Moreover, (21) is violated and (22) holds.

2.1 Let \( \tilde{H}(t, \tau) < H(t|p) \) so that \( \pi^*_i(\tau) \in [0, 1] \) and firm B continues if \( \pi_t \leq \pi^*_i(\tau) \); stops otherwise. Moreover, both (21) and (22) are violated.

2.2 Let \( \tilde{H}(t, \tau) < H(t|p) \) so that \( \pi^*_i(\tau) \in [0, 1] \) and firm B continues if \( \pi_t \leq \pi^*_i(\tau) \); stops otherwise. Moreover, (21) is violated and (22) is satisfied.

2.3 Let \( \tilde{H}(t, \tau) < H(t|p) \) so that \( \pi^*_i(\tau) \in [0, 1] \) and firm B continues if \( \pi_t \leq \pi^*_i(\tau) \); stops otherwise. Moreover, (21) is satisfied and (22) is violated.

In Lemmata 1, 2, and 3, we characterize the perfect Bayesian Nash equilibrium of the disclosure game. The equilibrium disclosure stage \( \tilde{\tau} \) is such that firm B continues until \( t = \tilde{\tau} - 1 \), firm A discloses at \( t = \tilde{\tau} \), and firm B’s beliefs are consistent with firm A’s choices. By assuming (6) and (9) satisfied, both firms will continue after disclosure. Lemma 1 applies to cases 1.1, 1.3, and 2.2 in which (22) is satisfied in
equilibrium. Disclosure stage \( \tau^* \) is firm A’s optimal and unconstrained disclosure as defined in Proposition 2.

**Lemma 1.** Let condition (22) be satisfied for equilibrium disclosure \( \tilde{\tau} \).

1. If (i) the LHS in (21) is decreasing in \( t \), (ii) there exists an odd integer \( t' \geq 1 \) such that (21) is violated for \( t \leq t' \) and (21) is satisfied for all \( t > t' \), and (iii) \( \pi < \pi_t^*(\tau^*) \), then disclosure is at \( \tilde{\tau} = t' \).

2. If otherwise, \( \tilde{\tau} = \max_{\tau'} \{ \tau' \in \{3, 5, \ldots, \tau^*\} : (22) \text{ is satisfied for } \tau = \tau' \forall t < \tau' \} \).

The result in Lemma 1 does not depend on whether firm B prefers a patent holder firm A (\( \tilde{H}(t, \tau) > H(t|p) \)) over a non-patent holder firm A (\( \tilde{H}(t, \tau) < H(t|p) \)). An equilibrium with optimal disclosure in \( \tau^* \) is feasible for both situations. In Lemma 1 we consider the case in which (22) is always satisfied and discuss the resulting equilibrium depending on whether (21) is violated. In Lemma 2 we consider the case in which no \( \tilde{\tau} \) as defined in Lemma 1 exists, in particular, we focus on the case in which (22) and (21) are not satisfied in equilibrium.

**Lemma 2.** If no such \( \tilde{\tau} \geq 3 \) as defined in Lemma 1 exists, and (21) and (22) are violated for all \( t \), then equilibrium disclosure is characterized as follows:

1. Equilibrium disclosure is in \( \tilde{\tau} = \tau' \) where \( \tau' \) is the highest \( \tau \geq 3 \) such that \( \pi \leq \min \{\pi_t^*(\tau) : \text{for all } t < \tau\} \),

2. If no such \( \tau' \geq 3 \) exists, then disclosure is in \( \tilde{\tau} = 1 \).

Finally, in Lemma 3, we assume that (22) is violated and (21) is satisfied in equilibrium and characterize the conditions under which firm A will immediately disclose.

**Lemma 3.** If no such \( \tilde{\tau} \geq 3 \) as defined in Lemma 1 exists, (21) is satisfied and (22) is violated, then equilibrium disclosure is at \( \tilde{\tau} = 1 \). In perfect Bayesian Nash
equilibrium, firm A discloses in $t = 1$ and continues in all odd $t > 1$; firm B continues in all even $t$.

Lemma 3 has an interesting implication on the impact of the degree of product market competition on disclosure. For degrees of competition sufficiently high, such that (6) is satisfied, but (13) and (22) are violated, we observe immediate disclosure. This means firm A forsakes her rent-seeking possibilities. The intuition is straightforward. If competition is sufficiently fierce, firm B’s monopoly profits are relatively low. Because firm A can extract rents only from B’s monopoly profits—the parties’ profits from the market on which they compete are tiny or zero—if competition is fierce the gains from holdup are small, and more than outweighed by the gains from disclosing right away to increase the efficiency of the standardization process.

We have characterized the perfect Bayesian Nash equilibrium in the six cases listed in Remark 1. Combinations of these can be constructed to analyze further (and plausible) contingencies, however the resulting equilibria share the salient features of the equilibria discussed in the Lemmata above and do not add any insight to the main result of this section.

**Proposition 6.** Condition (22) is a necessary condition for the equilibrium disclosure timing to be unconstrained in an environment with Bayesian update: If (22), firm B has incentive to participate in the standardization process even when he expects A to be a patent holder.

Proposition 6 uses the results in Lemmata 1, 2 and 3 to establish the necessary condition for disclosure to be at $\tau^*$, as determined in Proposition 2, and unconstrained by awareness. In particular, if (22) is not satisfied (as in Lemmata 2 and 3) disclosure at $\tau^*$ is either unfeasible or depends on the value of firm B’s prior beliefs. However,
even if (22) holds, Lemma 1 shows that disclosure may still not be at $\tau^*$, depending on condition (21).

Due to the importance of (22) in this setting, it is instructive to discuss how the validity of the condition is affected by three of the deep parameters of the model, $p$, $\alpha$ and $\theta$, for a given equilibrium value of $\tau$. First of all, an increase of the degree of competition restrains the validity of (22), by increasing the RHS of the condition. At the same time, if $\alpha$ increases, then $\sigma$ rises and $\tilde{H}$ decreases, so to reduce the value of the LHS of the inequality. Intuitively, a stronger patent increases the leverage bargaining power of firm $A$ and exacerbates the expropriation problem faced by firm $B$. Finally, the impact of SSO baseline productivity $p$ on (22) is ambiguous: On the one hand, an increase in $p$ reduces the uncertainty on the continuation of the conversation, on the other hand, a higher $p$ implies a higher probability to get to the disclosure stage, $\tau$, after which $A$ will extract a fraction $\sigma$ of $B$’s profits. The balance of these two forces determines the final outcome.

The above results hold if the firms continue the standardization process once firm $A$ has disclosed the patent, i.e., (6) is satisfied. For the final result, let (6) be violated. This implies that once the patent is disclosed, firm $B$ will not continue.

**PROPOSITION 7 (Constrained Disclosure).** Let condition (6) be violated for some $t > \tau \geq 1$, then firm $A$ will stop at $t = 1$.

Proposition 7 complements the considerations made after Lemma 3 regarding the role of product market competition. It shows that for a very high degree of competition, so that even (6) is violated and post-disclosure communication cannot be sustained, the standardization process is never initiated. Consider the parameterization introduced in Section 3. For all $\frac{1+\beta q}{2} \geq \theta > \beta q$, the parties jointly benefit from standardization but, in a noncooperative game, cannot sustain the process.
6 Concluding Remarks

We have presented a model of communication with asymmetric information, based on the work by Stein (2008), with which we endogenize the magnitude of patent holdup to study the effect on the timing of patent disclosure of patent strength, the productivity of industry standard setting, and competition. We find that late disclosure is more likely in more productive standard setting organizations and in less competitive industries. The intuition for the former result is that delaying patent disclosure increases the patent holder’s bargaining leverage, which in turn results in higher license fees the more valuable the standard is. The latter result arises from the observation that rent extraction via opportunistic licensing is the more profitable the higher are the firms’ market profits.
References


A Appendix

Proof of Proposition 1

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

\[
EU^C(\text{continue @} t) < U^C(\text{stop @} t) \tag{A.1}
\]

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

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

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

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

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

Proof of Proposition 2

Proof. For the sake of this proof, we assume that \( t \in (0, 1) \subset \mathbb{R}_+ \), so that \( t \) draws on real numbers bigger than unity. This simplifies the analysis without loss of generality. Moreover, for notational simplicity, let \( E_t(\text{@t}) := E_t U_A(\text{disclose @t}) \) and \( E_t(\text{@t+2}) := E_t U_A(\text{disclose @t+2}) \). Consider the following properties of the expected payoff functions \( E_t(\text{@t}) \) in equation (10) and \( E_t(\text{@t+2}) \) in equation (11).

**P1.** \( E_t(\text{@t}) \) and \( E_t(\text{@t+2}) \) are strictly increasing in \( t \) because \( \sigma(\alpha, t) \) (for \( \alpha > 0 \)), \( h(t) \), \( h(t + 1) \), and \( H(t|q) \) are strictly increasing in \( t \).
P2. Because \( \lim_{t \to \infty} h(t + k) = 1 \) for all \( k \geq 0 \) and \( \lim_{t \to \infty} \sigma(\alpha, t) = \alpha \), we get

\[
\begin{align*}
\lim_{t \to \infty} E_t(\@t) &= (1 - \theta) (1 + \alpha), \\
\lim_{t \to \infty} E_t(\@t + 2) &= (1 - \theta) (1 + p^2 \alpha),
\end{align*}
\]  
(A.2)  
(A.3)

P3. The value of \( E_t(\@t) \) lies in a bounded space,

\[ E_t(\@t) \in [E_1(\@1), E_\infty(\@\infty)) \]

with \( E_1(\@1) = (1 - \theta) H(1|q) > 0 \).

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

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

**Lemma A.2.** If \( E_1(\@1) < E_1(\@3) \), then there exists a finite value \( \hat{t} > 1 \) such that \( E_t(\@t + 2) \leq E_t(\@t) \) for all \( t \geq \hat{t} \) and \( E_t(\@t + 2) > E_t(\@t) \) for all \( t < \hat{t} \).

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

**Lemma A.3.** The assumption that \( E_t(\@t) \) and \( E_t(\@t + 2) \) intersect at most once implies that if condition (18) does not hold and \( E_1(\@1) > E_1(\@3) \) then \( E_t(\@t) \geq E_t(\@t + 2) \) for all \( t \geq 1 \).

*Proof. By Lemma A.1. This situation is depicted in panel (b) of Figure 2. Q.E.D.*

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

**P4.** Expected payoffs \( E_t(\@t + 2) \) can be rewritten as an increasing function of \( E_t(\@t) \):

\[ E_t(\@t + 2) := p^2 \rho(E_t(\@t)) \]

(A.4)

with

\[ \rho(E_t(\@t)) := E_t(\@t) + (1 - \theta) \left( \phi + \sum_{k=0}^1 p^k (1 - p) h(t + k) \right) \]

(A.5)

where

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

and

\[ E_{t+2}(\@t + 2) = E_t(\@t) + (1 - \theta) \phi = (1 - \theta) (1 + \sigma(\alpha, t + 2)) H(t + 2|q). \]
With property \( \textbf{P4} \) we can formulate firm \( A \)'s present value maximization problem in a recursive fashion. For further notational simplicity, let \( D := E_t(\hat{t}) \) and \( \rho(D) := \rho(E_t(\hat{t})) = E_t(\hat{t} + 2)/p^2 \). Consequently, the problem of firm \( A \) can be rewritten as

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

Moreover, let \( D = E_1(\hat{1}), \hat{D} = E_t(\hat{\hat{t}}), \) and \( \rho(\hat{D}) = E_t(\hat{\hat{t}} + 2)/p^2 \) with \( \hat{\hat{t}} \) defined in Lemma A.2. In \( \mathcal{P} \), \( D \) is the state variable and the objective is to determine the timing of disclosure. Three of the necessary conditions, guaranteeing that a fixed point that solves \( \mathcal{P} \) exists and is unique (Stokey and Lucas, 1989), hold true:

\textbf{NC1.} \( D \) takes values in a bounded set [by \( \textbf{P3} \)]

\textbf{NC2.} \( \rho(D) \) is increasing in \( D \) [by \( \textbf{P4} \)]

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

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

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

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

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

For \textbf{Case (ii)} we assume \( \rho(D) \geq D \) (i.e., equation (18) holds) and \( E_t(\hat{t}) \) and \( E_t(\hat{\hat{t}} + 2) \) intersect at most once. Referring to \textbf{NC3}, this is the case if

\[
\forall D > \hat{D} : p^2 \rho(D) < D \quad \text{and} \quad \forall D < \hat{D} : p^2 \rho(D) > D.
\]

The contraction mapping theorem can be applied and a simple stopping rule exists. To show this, we first prove that Blackwell’s monotonicity and discounting conditions are satisfied (Blackwell, 1965). An operator \( T \) is a contraction mapping if the following two conditions hold:\textsuperscript{21}

\textsuperscript{21}In the following we use \( f(\cdot) \) and \( g(\cdot) \) to denote the candidate solution to our functional fixed point problem.

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

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

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

Discounting is satisfied because the following holds:

\[
\max \{D, p^2[f(\rho(D)) + a]\} \leq \max \{D + p^2a, p^2[f(\rho(D)) + a]\} = \max \{D, p^2[f(\rho(D))]\} + p^2a.
\]

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

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

1. Assume \( \forall D > \bar{D} : f(D) \leq D \). Then

\[
\max \{D, p^2 f(\rho(D))\} \leq \max \{D, p^2 f(D/p^2)\} = p^2 \max \{D/p^2, f(D/p^2)\} = \bar{D},
\]

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

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

\[
\max \{D, p^2 f(\rho(D))\} \geq \max \{D, p^2 f(D/p^2)\} = p^2 \max \{D/p^2, f(D/p^2)\} = p^2 f(D/p^2) > p^2 D/p^2 = D.
\]

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

Therefore, the optimal rule prescribes disclosure if and only if

\[
\forall D \geq \bar{D} : \rho(\bar{D}) = \bar{D}/p^2.
\]

Strictly speaking, such a rule suggests to disclose at the lowest \( t \geq \hat{t} \), where \( \hat{t} \) is defined in Lemma A.2 and \( t \) an odd integer. Q.E.D.
Proof of Proposition 3

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

$$E_1U_A(disclose@1) \leq E_1U_A(disclose@3).$$

After some manipulation, we can rewrite this as

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

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

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

This expression can be rearranged to read

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

and, by the definition of $H(t|q)$ in equation (5) for $t = 1$ and $t = 3$,

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

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

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

If

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

then (A.8) holds with strict equality and condition (18) in Proposition 2 is violated for $\alpha = 0$. We can rewrite (A.9) as

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

It holds if

$$H(3|q) - h(2) > 0. \quad (A.10)$$
Because $H(3|q) = (1 - q) h(3) + \sum_{k=1}^{\infty} q^k (1 - q) h(3 + k)$, (A.10) holds true if and only if

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

We can further expand the summation to get

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

and

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

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

**Proof of Proposition 4**

*Proof.* We prove the claim by applying the intermediate value theorem. First, note that

$$E_t U_A(\text{disclose}@1) - E_t U_A(\text{disclose}@3),$$

or

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

is strictly positive for $q > 0$ and $p = 0$. The expression in (A.11) can be rewritten\(^{22}\) as

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

This inequality holds by equation (6) for $t = 1$ and because $\theta > 0$ and $h(0) = 0$. Note that equation (6) holds by equation (13), which is the underlying assumption of this section’s analysis.

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

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

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

\(^{22}\)Note, that $\lim_{p \to 0} p^0 = 1.$
with respect to $p$,

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

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

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

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

**Proof of Proposition 5**

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

$$F := E_t U_A(disclose@\hat{t}) - E_t U_A(disclose@\hat{t} + 2) = 0.$$  

We can define $\tau$ as

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

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

By the implicit function theorem,

$$\frac{d\hat{t}}{dp} = - \frac{\partial F}{\partial p} \bigg/ \frac{\partial F}{\partial \hat{t}}$$

and

$$\frac{d\hat{t}}{d\alpha} = - \frac{\partial F}{\partial \alpha} \bigg/ \frac{\partial F}{\partial \hat{t}}.$$  

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

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

Hence,

$$\frac{d\hat{t}}{dp} = - \frac{\partial F}{\partial p} \bigg/ \frac{\partial F}{\partial \hat{t}} > 0$$

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

For the effect of $\alpha$ on $\hat{t}$, we find that
\[
\frac{\partial F}{\partial \alpha} = (1 - \theta) \left[ \frac{\partial \sigma(\alpha, \hat{t})}{\partial \alpha} H(\hat{t}|q) - p^2 \frac{\partial \sigma(\alpha, \hat{t} + 2)}{\partial \alpha} H(\hat{t} + 2|q) \right].
\]
This expression is negative, and $d\hat{t}/d\alpha > 0$, if and only if condition (19) holds true. Q.E.D.

**Proof of Lemma 1**

Proof. For the proof of Lemma 1 we consider only cases 1.1, 1.3, and 2.2 in which (22) is satisfied. We begin with the second claim, and proof the first claim and we move along. We first consider $\tau' = \tau^*$ and then generalize to any $\tau' \in \{3, 5, \ldots, \tau^*\}$.

**Case 1.1** Suppose $\tau = \tau^*$. Because (21) is satisfied (for all $t$), meaning (13) is violated, a non-patent holder $A_0$ will not continue. Firm $B$ anticipates this, and updates his beliefs to $\pi_t = 1$ if observing a firm $A$ continuing in $t - 1$. Firm $A$ in return, by Proposition 2 prefers continue over disclose, and anticipates that if he continues firm $B$ will update his beliefs and continue because $\pi_t = 1 \geq \pi^*_t(\tau^*) \in [0, 1]$. As a matter of fact, in perfect Bayesian Nash equilibrium (PBE) firm $A$ will continue in $t = 1$, firm $B$ updates beliefs $\pi_2 = \pi_4 = \ldots = 1$ and continues until $t < \tau^*$. Firm $A$ discloses in $\tau = \tau^*$.

**Case 1.3** Suppose $\tau = \tau^*$. Because (21) is violated (for all $t$), $\pi^*_t(\tau^*) < 0 \leq \pi_t$ for all $t$, firm $B$ will continue irrespective of firm $A$’s actions. In PBE, firm $A$ continues in all odd $t < \tau^*$, firm $B$ continues in all even $t < \tau^*$ for any $\pi$, and firm $A$ discloses in $\tau = \tau^*$.

We can now combine the analysis of cases 1.1 and 1.3 to prove claim 1 in the following way. For simplicity of the argument, we assume that given $p$, the LHS of (13) is either monotonically non-decreasing in $t$ or monotonically non-increasing in $t$. This assumption, however, is without loss of generality.

1. Suppose (21) satisfied for some $t$ and violated for some $t$. More specifically, suppose (21) is satisfied for low $t$ and violated for high $t$ so that condition (ii) in claim 1 does not hold. This applies if the LHS in (21) is increasing in $t$. (21) satisfied for low $t$ implies that it is satisfied for $t = 1$; and only a patent holder is willing to continue. If at $t = 2$ firm $B$ has observed continue at $t = 1$, he can infer that firm $A$ is a patent holder, and updates his beliefs so that $\pi_2 = \pi_4 = \ldots = 1$, implying that firm $B$ continues for all even $t < \tau^*$. Whether or not (21) is satisfied or violated for higher $t$ is irrelevant. As mentioned earlier, a non-patent holder $A_0$ has no incentive in prolonging the standardization process (by equation (13) violated) and will therefore not mimic a patent holder; firm $B$ anticipates this and correctly infers that he will observe continue only if firm $A$ is a patent holder.

2. Suppose (21) is violated for low $t$ and satisfied for high $t$ so that condition (ii) in claim 1 holds. As discussed in case 1.3, if (21) is violated for low $t$, then $\pi^*_t(\tau^*) < 0$ and firm $B$ will continue for any $\pi$. Let $t'$ the highest $t$ for which (21) is violated and $t' + 1$ the one for which (21) is satisfied. If $t'$ is even so that condition (i) in claim 1 does not
hold. Then (21) is violated for an odd $t' - 1$ when $A$ moves and violated for an even $t'$ when $B$ moves. Case 1.3 applies. In the odd $t' + 1$ when $A$ moves and $t' + 2$ when $B$ moves, case 1.1 applies.

3. Suppose $t'$ is odd (so that both conditions (i) and (ii) in claim 1 hold): Then (21) is violated (and a non-patent holder will want to continue) in $t'$ but is satisfied in $t' + 1$ when $B$ moves. This implies that from $A$’s move, $B$ cannot infer $A$’s type, and in $t'$ will not continue for all $\pi_t$ but only if $\pi_t \geq \pi_t^*(\tau^*) \geq 0$. Up to $t'$, $B$ has not been able to update his beliefs, so that $\pi_t = \pi$. If $\pi \geq \pi_t^*(\tau^*) \geq 0$, then $B$ continues in $t' + 1$, and $A$ continues in $t'$ anticipating $B$’ continuation. For all $t > t' + 2$, case 1.1 applies.

If, on the other hand, $\pi < \pi_t^*(\tau^*)$ so that condition (iii) in claim 1 holds, $B$ stops in $t' + 1$, and $A$ discloses in $t'$. This establishes the proof of claim 1.

Case 2.2 Suppose $\tau = \tau^*$. Because (22) is satisfied, $\pi_t^*(\tau^*) > 1 \geq \pi_t$ for all $t$. Because for $H(t, \tau) < H(2|p)$, firm $B$ continues if $\pi_t \leq \pi_t^*(\tau^*)$, he continues for all $\pi_t$. In PBE, firm $A$ continues in all odd $t < \tau^*$, firm $B$ continues in all even $t < \tau^*$ for any $\tau$, and firm $A$ discloses in $\tau = \tau^*$.

The above steps apply to any $\tau' \leq \tau^*$. As long as $\tau^*$ has not been reached, firm $A$ prefers later disclosure over earlier disclosure. If condition (22) is satisfied for $\tau = \tau'$ for all $t < \tau'$, then this $\tau'$ is candidate for an equilibrium. We stress candidate, because if two or more $\tau' \leq \tau^*$ render (22) satisfied for all $t < \tau'$, then the highest of these $\tau'$ will be the disclosure stage in PBE. Suppose $\tau_1' < \tau_2'$. At $t = \tau_1'$, firm $A$ will continue to disclose at $\tau_2'$, and firm $B$ will continue anticipating disclosure at $\tau_2'$. Q.E.D.

Proof of Lemma 2

*Proof.* 1. For the proof, case 2.1 applies. We first consider $\tau = \tau^* = 5$. The presented arguments can be readily extended to any $\tau = \tau^*$, and generalized to any $\tau = \tau' \leq \tau^*$.

Suppose $\tau^* = 5$: We are interested in $B$’s behavior in $t = 2, 4$, and $A_0$ and $A_1$’s behavior in $t = 1, 3$. In $t = 2$, $B$’s beliefs are denoted by $\pi_2$, his beliefs in $t = 4$ are denoted by $\pi_4$. We start with the second round ($t = 3$ and $t = 4$) and then move forward to the first round ($t = 1$ and $t = 2$).

We assume $\tilde{H}(4,5) < H(4|p)$ (condition for the claim), so that $B$ continues if $\pi_4 \leq \pi_4^*(5)$ and stops if $\pi_4 > \pi_4^*(5)$. In $t = 3$, if $A_1$ anticipates $B$ to continue, $A_1$ will continue. If $A_1$ anticipates $B$ to stop, $A_1$ will disclose. $A_1$’s decision in $t = 3$ depends on $\pi_4$. Suppose $\pi_4 \leq \pi_4^*(5)$ so that $B$ continues, and $A_1$ continues anticipating $B$ continuing. If $B$ in $t = 4$ has not observed disclosure, then it is because firm $A$ is a non-patent holder $A_0$ (because (21) is violated by condition for the claim, a non-patent holder prefers continue over stop) or a patent holder $A_1$ (and no disclosure because $B$ continues so that $A_1$ continues). This means, firm $B$ does not learn from firm $A$’s behavior firm $A$’s type. The posterior belief $\pi_4$ is thus equal to the posterior belief $\pi_2$, $\pi_4 = \pi_2$. Hence, if $\pi_2 \leq \pi_2^*(5)$, then firm $B$ continues in $t = 4$ and firm $A_1$ continues in $t = 3$, so that firm $B$’s beliefs in $t = 4$ are $\pi_2 \leq \pi_4^*(5)$. Firm $A_1$ eventually discloses at $\tau = \tau^* = 5$.

Moving up one round, we assume $\tilde{H}(2,5) < H(2|p)$ (condition for the claim). Let $\pi_2 \leq \pi_2^*(5)$ so that $B$ continues, and $A_1$ continues anticipating $B$ continuing. If $B$ in
t = 2 has not observed disclosure, then it is because firm A is A₀ or firm A is firm A₁ (and no disclosure because B continues so that A₁ continues). This means, firm B does not learn from firm A’s behavior firm A’s type. The posterior belief π₂ is thus equal to the prior belief π, π₂ = π. Hence, if π ≤ π₂*(5), then firm B continues in t = 2 and firm A₁ continues in t = 1, so that firm B’s beliefs in t = 2 are π ≤ π₂*(5).

Moreover, if not only π ≤ π₂*(5) (so that A₁ continues in t = 1 and B continues in t = 2) but also π = π₂ ≤ π₂*(5) (so that A₁ continues in t = 3 and B continues in t = 4), then both players will continue until t = 5 when the patent holder A₁ discloses. Hence, assuming that \( H(2, 5) < H(2|p) \) and \( H(4, 5) < H(4|p) \), if π ≤ π₂(5) and π ≤ π₂*(5) or π ≤ min \{π₂*(5) : t = 2, 4\}, then A₁ discloses in t = τ* = 5.

The very same structure applies to τ* = 7, τ* = 9, and so forth. Hence, if for τ = τ* the prior belief is π ≤ min \{π₂*(τ*) : ∀even t < τ*\} so that B always continues as π is always smaller than π₂*(τ*) for all even t, then A will disclose in \( \tilde{\tau} = τ* \). More generally, if for τ = τ' ≤ τ*, the prior belief is π ≤ min \{π₂*(τ') : ∀even t < τ'\}, in PBE the firms will continue in all t and firm A discloses in τ'. If more such values τ' exist, then the PBE is such that disclosure is in latest of this candidates, \( \tilde{\tau} = \max \{\tau'\} \).

2. If no such τ' ≥ 3 exists then π ≥ π₂*(3). In t = 2, firm B will stop, and firm A discloses in \( \tilde{\tau} = 1 \). Q.E.D.

**Proof of Lemma 3**

Proof. Cases 1.2 and 2.3 apply. In case 1.2, firm B continues if π₁ ≤ πₙ*(τ). Because (22) is violated for any τ, πₙ*(τ) 1 so that firm B always stops, irrespective of firm A’s choice. Firm A thus chooses to disclose in t = 1. In case 2.3, firm B continues if π₁ < πₙ*(τ). Because (21) is violated so that πₙ*(τ) < 0, firm B always stops, irrespective of firm A’s behavior. Firm A thus chooses to disclose in t = 1. Q.E.D.

**Proof of Proposition 7**

Proof. If (6) does not hold, then (13) and (17) do not hold. Moreover, (21) is satisfied and (22) is violated. By Lemma 2, if A does not disclose in t = 1, then B stops in t = 2; and continue is dominated by disclose. Firm A’s payoffs if she stops at t = 1 are \( U_A(\text{stop@1}) = (1 - \theta) h(1) + \theta[h(1) - h(0)] = h(1) \). Her payoffs for disclosure at t = 1 are \( E_A(\text{disclose@1}) = (1 - \theta) h(1) \). For all θ > 0, \( U_A(\text{stop@1}) > E_A(\text{disclose@1}) \), and firm A stops in t = 1. Q.E.D.