Conversation With Secrets*

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Abstract

We analyze the sustainability of a conversation when one agent might be endowed with a piece of private information that affects the payoff distribution to its benefit. Such a secret can compromise the sustainability of conversation. Even without an obligation, the secret holder will disclose its secret if it prevents preemptive termination of the conversation. The non-secret holder lacks this possibility and stops the conversation. Competition and limited effectiveness of the conversation amplify this result of early disclosure and render the conversation process less sustainable. We discuss policy and managerial implications for industry standard development and joint ventures.

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1 Introduction

Information is a valuable resource (Stigler, 1961) and information exchange fosters scientific progress and the accumulation of knowledge. Innovation often begins with an initial idea that must be shared with others to allow for further improvements. Likewise, business ventures may begin when an entrepreneur shares an idea for a novel initiative which subsequently develops through the exchange of further *ideas* for improvements. Stein (2008) studies the sustainability of such conversations that build upon a preliminary idea through exchange of new ones. In this context, a conversation is a collaborative exchange of *ideas* between competing agents for the purpose of improving the value of a technology or a business venture. Similarly, Hellmann and Perotti (2011) examine organizational forms in which such ideas are generated, circulated, and completed. We build upon this approach and study how the sustainability of this innovation process through exchange of ideas is affected when one party holds a *secret* whose disclosure is a strategic decision.

We define a *secret* as a piece of private information that is payoff-relevant. It allows its holder to extract larger rents from the conversation at the expense of the other agents. For example, a secret could be a patent protecting one of the essential technologies comprising the innovation under development. In the business venture example, a secret could be an exclusive contract over the supply of an essential input. An *idea*, whose exchange is at the heart of the conversation, is a privately observed piece of information that increases the value of the conversation. Different from a secret, affecting only the distribution of payoffs, if an idea is shared it increases both agents' payoffs. On the other hand, if an idea is not shared it increases only its holder's payoffs.

The following example from Wade (1980) and Nelkin (1982) illustrates the working of secrets and the strategic tensions they may give rise to. In 1977, research hematologists at the *University of California School of Medicine* were working on a sample of cancerous bone marrow cells. Scientists succeeded in creating a new cell line that was found to produce interferon. At this stage, they held a half-baked (and unprotected) discovery in their hands and decided to share it with a colleague at a *Hoffmann-La Roche* funded research center. Using the shared information, their colleague developed an optimal medium for interferon production which he then passed on to Hoffmann-La Roche for a profitable business project. In this example, an initial idea is exchanged by agents that share a common interest in the quest for scientific knowledge, but compete on the extraction of the resulting rents. The last scientist had concealed that researchers affiliated with Hoffmann-La Roche had been working on a patent application and needed an effective medium for the production of interferon. Eventually, the exchange of information resulted in the advancement of knowledge, however, by effect of the secret the University of California was deprived of potential licensing rents. Wade (1980:1494) concludes that such rent expropriation has "the capacity to strain and rupture the informal traditions of scientific exchange." Similarly, Donald Kennedy, then president of Stanford University, predicts that "the fragile network of informal communication that characterizes every especially active field is liable to rupture" (cited in Nelkin, 1982:706).[1]

We develop a formal model to shed light on conversation incentives when one of the agents may or may not hold a secret. We ask: What is the impact of secrets and the disclosure of those secrets on the sustainability of the conversation? Also, when does the secret holder disclose its secret? We address these questions by means of a dynamic model with asymmetric information that builds upon the conversation model in Stein (2008) where two agents, A and B, take turns in suggesting new ideas that increase the value of the conversation. Agents may be competitors, and if one does not share its new idea it obtains a competitive advantage over its rival (due, e.g., to larger consumers' reservation value or productive efficiency). Our analytical framework builds on three key assumptions: *First*, as in Stein (2008) or Hellmann and Perotti (2011), ideas are complementary insofar as an agent can find a new idea *only* if the other agent has suggested an idea in the previous round. *Second*, agent A but not agent B may be endowed with a secret. This is private information, fully verifiable if disclosed,[2] and implies a *secret-holder* and a *non-secret holder* agent A type. *Third*, the secret holder can extract a share of agent B's

[1] Law suits were dropped after Hoffmann-La Roche had paid an undisclosed sum (Culliton, 1983).

[2] *Ex-ante* verifiability of a secret implies that a non-secret holder A cannot lie and claim to have a secret.

product-market profits. This share reflects the secret holder's bargaining leverage in *ex-post* negotiations. It is endogenously determined by assuming an increased bargaining leverage the later the secret holder discloses its secret.

When there is no secret the conversation is always sustainable if the two agents are not in competition (Proposition 1, as in Stein (2008)). When a secret has been disclosed the conditions for sustainable conversation are even *less* restrictive (Proposition 2). The actual existence of a secret therefore has a positive effect on conversation. However, when the secret has not been disclosed, this outcome ceases to apply. In our baseline model with private information about a secret there is no obligation to disclose,[3] i.e., the secret holder can disclose *ex post* (after the end of the conversation) and fully exploit its bargaining leverage without incurring any costs.

We proceed considering the ideal case in which a secret holder A anticipates agent B to always share its ideas (and by the complementarity assumption keep conversation alive). It is then in A's best interest to always contribute as well but disclose the secret as late as possible (Lemma 1). In this scenario conversation is always sustainable and ends only when a new idea fails to arrive at which point the secret will be disclosed (*ex-post* disclosure). However, as we shall argue below, when a secret holder cannot rely on agent B to always share its ideas, in equilibrium the secret holder may be inclined to disclose *ex ante*, i.e., before the end of the conversation. Whether or not A can rely on B's conversation incentives depends on agent B's beliefs about whether A holds a secret.

When agent B expects agent A to hold a secret with sufficiently low probability, then private information by way of a secret does not affect the sustainability of conversation. Agent B's conversation incentives are indeed not binding and the secret holder can delay disclosure—and thus maximize the rents extracted—until after the conversation ends. However, when agent B expects with high probability to face a secret holder (and thus expects with high probability to have a fraction of its product-market profits extracted), the secret holder will in equilibrium

[3]This initial assumption relates our model to Grossman and Hart (1980) who study voluntary disclosure of information when lying is illegal (in our model lying is not effective due to *ex-ante* verifiability, i.e., a lie would be detected immediately) and no positive disclosure laws are in place (in our model the secret holder has no obligation to disclose).

decide to disclose the secret and relinquish its private information to salvage the conversation process. This result is driven by the observation that, absent disclosure, agent B is inclined to preemptively terminate the conversation. Facing the threat of termination, a secret holder discloses to allow for the conversation to continue.

For this type of revelation (or signaling) game, we derive a *separating equilibrium* in which the secret-holder discloses the secret and the non-secret holder agent A (not having a secret to disclose) terminates the conversation (Proposition 3). This equilibrium survives the *Intuitive Criterion* and *D1* (Cho and Kreps, 1987), as standard refinements of perfect Bayesian equilibria, when the agents are direct competitors in the product market. The intuition is simple: If agents compete, when agent B is to stop the conversation absent disclosure, then the secret holder agent A discloses to allow for the conversation to continue and the non-secret holder agent A stops to gain a product-market advantage. For the scenario in which the agents are not directly competing in the product market, we characterize a *hybrid equilibrium* in which the secret holder discloses the secret to salvage the conversation with a probability strictly between zero and one (Proposition 4).

These results warrant a few words of discussion. The secret holder reveals the secret when agent B has sufficiently high beliefs that A is endowed with a secret. In other words, the secret holder relinquishes its private information when in expectation such private information is sufficiently costly for agent B. Note that there is no obligation for the secret holder to disclose. Not disclosing comes only at the indirect cost of lower payoffs from conversation as it may induce agent B to terminate preemptively. At the same time, the mere possibility that a secret exists creates an inefficiency that is standard in models of asymmetric information. Because the non-secret holder A cannot credibly communicate its secret, in the separating equilibrium the conversation comes to an end when agent A does not hold a secret. From an *ex-ante* perspective, then, private information about how the returns of a conversation are shared negatively affects the sustainability of a conversation. A similar logic applies in the hybrid equilibrium. We show that this inefficiency is the more likely to arise the fiercer the competition between the agents and the less effective the conversation, i.e., the slower the flow of new ideas (Proposition 5).

To show that the intuition behind our separating equilibrium extends to a setting that dispenses with the assumption that the existence of the secret implies the disclosure of its terms, we study a scenario in which the existence of the secret is common knowledge but its terms are not. We find that the secret holder conceals the terms of the secret until the other agent B threatens to stop the conversation. At that point, the secret holder discloses to rescue the conversation (Proposition 7). However, unlike in the previous scenario, the conversation is always sustainable along the equilibrium path when a secret's existence is common knowledge.

Our framework provides a general model of conversation with secrets. We discuss two specific applications: *industry standard development* and *business (or joint) ventures*. In *industry standard development*, a prominent approach in the literature on standard-setting is to model the process as one of *ex-post* coordination on one out of a number of competing, existing technologies. However, Farrell and Saloner (1988:250) observe that "participants [in a standard-setting process] are often engineers who share information and view the committee as a design process, and pursue an 'ideal technology'." We provide a model of *ex-ante* cooperation that addresses this function of standard-setting organizations (SSOs). Our approach complements the existing literature on the functioning of SSOs (Rosenkopf, Metiu, and George, 2001; Simcoe, 2012b; Farrell and Simcoe, 2012; among others).[4] The model captures the salient features of industry standard development and provides novel insights into the functioning of standard setting and the decision to disclose standard-essential patents. The results suggest that *ex-post* disclosure of essential patents is more prevalent in committees that are more effective in their development process and characterized by soft competition among its members. Conversely, ineffective committees with competitive members experience early termination of the development process and lower quality standards. We conclude the application by discussing *ex-ante license commitments* (e.g., *RAND* commitments), *implied waivers* of patent rights, and

[4]For a more general treatment of committees see Li, Rosen, and Suen (2001) or Visser and Swank (2007).

certificates as remedies of the inefficiency caused by private information about the existence of standard-essential patents.

Business (or joint) ventures are another example for conversation among competitors when there is *ex-ante* asymmetric information. We apply our framework to the question of how sustainable a joint venture is in the presence of asymmetric information. In our illustration, private information held by one of the partners is a secret exclusive contract over the supply of an essential input. Through this, the secret holder can *ex post* extract side payments from its partner. If the exclusive contract were to be disclosed early on, then the partner would not be subject to *ex-post* opportunism in the terms of the partnership or could insist on a business design that allows for substitute inputs. As before, the model predicts inefficient termination of ventures for fiercer competition between the partners and a lower potential value of the partnership. We briefly discuss some results from the management literature that are consistent with our theoretical findings.

Our model is related to the literature on disclosure of (protected and unprotected) ideas and rent expropriation. One strand of this literature has focused on the role of information disclosure in innovation processes, developing on the seminal work by Arrow (1962) and his "disclosure paradox." In an environment where intellectual property protection is poor or absent, Anton and Yao (1994) show how inventors can limit the risk of expropriation of their ideas from users by means of contingent contracts, and Anton and Yao (2002) show that innovators can engage in partial disclosure to optimally sell their ideas. Finally, Gans, Murray, and Stern (2011) determine the conditions under which it is optimal to disclose scientific knowledge via publication, patenting, or both. A second strand of the literature studies the incentives of agents with competing interests to exchange information. Stein (2008) studies the sustainability of such conversation between competitors and Hellmann and Perotti (2011) look at the performance of different organizational forms (firms versus markets) in fostering new ideas and technologies. Moreover, Dziuda and Gradwohl (2012) analyze agents' incentives to jointly develop a project under privacy concerns, in Augenblick and Bodoh-Creed (2012) agents exchange information about their types to determine whether a profitable match is viable, and Guttman, Kremer, and Skrzypacz (2012) study the problem of voluntary disclosure of multiple pieces of private information in a dynamic environment. We develop on both strands of the literature by studying how the sustainability of a communication process between competing agents through exchange of (unprotected) *ideas* is affected when a party in the conversation holds a (protected) *secret* and its disclosure is a strategic decision.

The paper is structured as follows: In Section 2 we present the model of conversation with secrets, in Section 3 we summarize the results on the sustainability of conversation without private information, in Section 4 we present the main results on conversation with private information and provide welfare effects. We discuss our results in the context of industry standard development and business ventures in Section 5. Section 6 concludes. The formal proofs of the results are relegated to Appendix A.

2 Model

2.1 Structure

Two agents, A and B, take actions in periods $t \geq 1$. Agent A moves in odd periods and agent B moves in even periods. The two agents are engaged in a conversation that requires the exchange of ideas.

DEFINITION 1 (Idea)**.** *An idea is a payoff relevant and privately observed piece of information. If shared, it has a positive effect on both agents' payoffs. If not shared it has a positive effect on the holder's payoffs and no effect on the non-holder's payoffs.*

Each period t consists of two sub-stages: In sub-stage 1 an *idea* arrives with probability $p_t \in [0, 1)$. Concurrently with its first idea, agent A may have a *secret*.[5] If no new idea arrives in this sub-stage, the game ends and payoffs are realized. If a new idea has arrived in sub-stage 1, then in sub-stage 2 agents take actions s_t. For our purposes a *secret* is defined as follows:

[5] Our results do not change qualitatively when asymmetric information is two-sided, i.e., both agents may have a secret (Ganglmair and Tarantino, 2012).

DEFINITION 2 (Secret)**.** *A secret is a payoff relevant and privately observed verifiable piece of information. It has a positive effect on the secret holder's payoffs and a negative effect on the other agent's payoffs.*

Our setup comprises two distinct types of private information. First, *ideas* arrive continually. If shared an *idea* has a positive impact on both agents' payoffs. However, the holder of an idea has a private incentive to conceal. For conversation to take place in each period, the sharing of this private information must be incentive compatible. Second, an agent may enter the game endowed with a *secret*. By observing the actions of a potential secret holder, the other agent can infer the existence of a secret. This second type of private information endogenously affects the distribution of final payoffs and may thus compromise the sustainability of the conversation.

[Figure 1 about here.]

The structure of the game when agent A is a secret holder is depicted in Figure 1. After an idea has arrived, in any given period $t \in T_B$ agent B can *continue (C)* the conversation by sharing the new idea with agent A. In this case the conversation proceeds to period $t+1 \in T_A$. Otherwise agent B can *stop (S)* the conversation by not sharing the idea, in which case the game ends and payoffs are realized. Here, T_A and T_B denote the sets of odd integers and even integers when agents A and B move. Agent B's action set is $\mathscr{B}_t = \{C, S\}$ if $t \in T_B$; it is $\mathscr{B}_t = \emptyset$ for $t \notin T_B$.

Agent A's action set in $t \in T_A$ depends on its type. For a non-secret holder, denoted by $A = A_0$, the action set is the same as for B, $\mathscr{A}_t = \{C, S\}$ if $A = A_0$. A secret holder, denoted by $A = A_1$, must also decide whether to reveal its secret, and this gives rise to three distinct actions. The secret holder can *disclose (D)*, which means share the new idea and reveal its secret.[6] We will refer to this as *ex-ante disclosure* since the secret is disclosed during the conversation. Second, the secret holder can *continue (C)* the conversation by sharing the new idea but not revealing the secret. In both D and C the conversation proceeds to the next

[6]Disclosure of the existence of the secret implies disclosure of the terms of the secret. This is an implication of *ex-ante* verifiability of the secret. We relax this assumption when we consider the case in which the existence of the secret is common knowledge but the terms of the secrets are not (Proposition 7).

period. Third, the secret holder can *stop (S)* the conversation by not sharing the new idea. In this case, the conversation ends and payoffs are realized. Once the secret holder has disclosed the secret, its action set is the same as a non-secret holder's:

$$\mathscr{A}_t = \begin{cases} \{C, D, S\} & \text{if } t \in T_A,\ A = A_1 \text{ before disclosure,} \\ \{C, S\} & \text{if } t \in T_A,\ A = A_0, \text{ or if } A = A_1 \text{ after disclosure} \\ \emptyset & \text{if } t \notin T_A, \end{cases}$$

Note that the secret is fully verifiable *ex ante*, implying that a non-secret holder agent A_0 cannot credibly claim that it *does* have a secret, nor can a secret holder credibly communicate that it *does not* have a secret.

We assume that whenever the conversation ends and the secret has not yet been revealed, the secret holder will disclose after the end of the conversation.[7] We refer to this as *ex-post disclosure*, which can occur when B stops, A_1 stops, or a new idea fails to arrive.

The probability with which a new idea arrives in sub-stage 1 of any given period t is

$$p_t(s_{t-1}) = \begin{cases} 0 & \text{if } s_{t-1} = S \\ p \in (0,1) & \text{if } s_{t-1} \in \{C, D\}. \end{cases} \tag{1}$$

This arrival process captures the complementarity in the production of ideas, as in Stein (2008) or Hellmann and Perotti (2011), that is, ideas foster the arrival of new ideas to be exchanged in conversation.

At the beginning of any given period $t \in T_i$, an agent $i = A, B$ observes the history $\Omega(t)$ of the actions taken in all periods $t' < t$,

$$\Omega(t) := \{s_{t'} | t' < t, s_{t'} \in \mathscr{A}_{t'} \text{ if } t' \in T_A \text{ and } s_{t'} \in \mathscr{B}_{t'} \text{ if } t' \in T_B\}. \tag{2}$$

The arrival of a new idea in t is privately observed. Moreover, agent A's type, i.e., whether or

[7] The reason for this assumption is the simple observation that, once the conversation has ended, revealing the secret is strictly dominant.

not it holds a secret, is private information. Agent B has a prior belief $\pi > 0$ that A holds a secret, and beliefs $\pi = Pr(A = A_1)$ and $1 - \pi = Pr(A = A_0) = 1 - Pr(A = A_1)$ are common knowledge. We solve this game of asymmetric information using perfect Bayesian equilibrium as the equilibrium concept and assuming that at any t agents cannot precommit to any actions taken in $t' > t$.

2.2 Payoffs

The payoffs are realized only after the conversation game ends. Suppose the agents are competitors and $\theta \geq 0$ is the degree of product-market competition. More specifically, suppose each agent is monopolist in a fraction $1-\theta$ of a unit-sized market and competes on the remaining fraction. Agent i's monopoly profits are $v(n_i)$, where n_i is the number of ideas to which the agent i has access.[8] The competitive profits depend on the agents' respective number of ideas: If they both have the same stock of ideas, $n_i = n_{-i}$, competition washes out the value of conversation and profits are equal to zero. If an agent i has an additional idea, $n_i = n_{-i} + 1$, then it has a competitive advantage and generates profits $v(n_i) - v(n_i - 1)$ in the competitive segment. An agent i's product-market profits are then

$$R_i = (1-\theta)\, v(n_i) + \theta \max\left\{0, v(n_i) - v(n_{-i})\right\}. \tag{3}$$

The function $v(n_i)$ is increasing at a diminishing rate, with $v(0) = 0$. It captures the product-market effects of conversation, which can be of one of two types: Either the conversation increases the consumers' reservation value of a good that agents produce at constant cost or it lowers the costs of production of a good for which consumers have a constant reservation value.

If agent A holds a secret, it can extract a fraction of B's product-market profits. Let $\sigma \in [0, 1]$ denote this fraction. This σ is common knowledge. It depends on the timing of disclosure, $\tau \in \mathbb{N}^+$, and is increasing in τ at a diminishing rate, with $\sigma(\tau) > 0$ for all $\tau > 1$ and $\sigma(1) = 0$. We can now specify the agents' payoffs arising from the conversation. The secret

[8] The number of ideas is the sum of the ideas generated by agent i and the ideas shared by agent $-i$.

holder's payoffs are $R_A + \sigma(\tau)R_B$ and agent B's payoffs are $(1 - \sigma(\tau))\, R_B$.[9] When there is no secret, the payoffs are equal to R_i for $i = A, B$.

In our application of the model to standard setting, holdup arises because of a problem of users' lock-in. Firms, e.g., in highly innovative and dynamic industries, invest in standard-specific technologies during the process because they expect the market for the final standard-based product to be short-lived. Only by such early investment can they capitalize on respective market opportunities.[10]

2.3 Conversational Equilibrium

We derive the conditions under which a *conversational equilibrium* can be sustained. Following Stein (2008), we define such an equilibrium as one in which agents always share new ideas. The conversation then continues until a new idea fails to arrive, with each agent having access to the same number of ideas, $n_i = n_{-i}$. We postulate such an equilibrium exists and verify that no agent has incentive to deviate. In particular, we look at the conditions under which a conversational equilibrium can be sustained in the absence and in the presence of secrets. Moreover, in the latter scenario we specify the timing of disclosure at equilibrium.

3 Conversation Without Secrets

We first present the benchmark case without a secret and characterize the conditions that sustain a conversational equilibrium in this environment. This means A does not hold any

[9]Because the secret induces the payment of a transfer equal to a share $\sigma(\tau)$ of agent B's product-market profits but affects neither the value of ideas nor the production of ideas, the joint value of conversation is independent of agent A's disclosure.

[10]See Farrell and Klemperer (2007) for a comprehensive review of the literature on lock-in and Shapiro and Varian (1998) for an applied view.

secret and this is common knowledge.[11] The model then boils down to the conversation model in Stein (2008) in which asymmetric information concerns only the arrival of a new idea.

In the model of conversation without secrets, agent i's payoffs under the conversational equilibrium are equal to $(1-\theta)\,V(t)$, where

$$V(t) \;=\; \sum_{k=0}^{\infty} p^k\,(1-p)\,v(t+k). \tag{4}$$

These payoffs are constructed as follows: Given agent i shares the idea in t, both agents have access to t ideas. With probability $(1-p)$, there will be no further ideas after time t, and agents' payoffs are $(1-\theta)\,v(t)$; with probability $p\,(1-p)$, there will be exactly one further idea after t, so payoffs are equal to $(1-\theta)\,v(t+1)$; with probability $p^2\,(1-p)$ there are exactly two further ideas, and so forth.

If in period t agent i decides to stop and not share its idea with agent $-i$, so that $n_i = t = n_{-i}+1$, its payoffs are equal to

$$(1-\theta)\,v(t) + \theta\,[v(t) - v(t-1)] = v(t) - \theta v(t-1). \tag{5}$$

Thus agent i in t chooses to continue the conversation by sharing its idea as long as

$$\frac{V(t) - v(t-1)}{v(t) - v(t-1)} \geq \frac{1}{1-\theta}. \tag{6}$$

For the conversational equilibrium to be sustainable, this condition must hold for *all* t.

PROPOSITION 1 (Stein (2008) (Proposition 2))**.** *A conversational equilibrium is sustainable if, and only if, condition* (6) *holds for all t. Condition* (6) *is less restrictive for more effective*

[11]In terms of our notation this *no-secret* scenario is equivalent to the one in which agent A reveals the secret (both existence and its terms) in $t=1$ so that $\tau = 1$ and $\sigma(\tau) = 0$. Comparing this benchmark with the results for a model of conversation with secrets helps us understand the effect that uncertainty about the existence of a secret has on the sustainability of conversation. In order to isolate the effect of uncertainty from the effect of the secret (with the bargaining leverage it provides) we will later introduce a benchmark in which the existence of the secret is common knowledge, however, its terms are unknown.

conversation processes (higher p) and a lower degree of competition (lower θ). For $\theta = 0$, the condition always holds.

Proposition 1 sets out the benchmark condition that determines the sustainability of the conversation in the absence of asymmetric information about the existence of a secret. The expected joint payoffs from the conversational equilibrium are

$$W = 2\,(1-\theta)\,V(1). \tag{7}$$

Note that because (6) always holds if $\theta = 0$, the conversational equilibrium in absence of a secret is always sustainable when the two agents are not in competition. We will show that this does not necessarily remain the case when there is asymmetric information about the existence of a secret. There agent B might threaten to (preemptively) stop the conversation even when it does not compete with agent A.

4 Conversation and Disclosure of Secrets

We now introduce the secret and analyze the role it plays in the conversation model. In this scenario agent B forms beliefs about agent A's type, namely whether or not agent A holds a secret. We proceed in three steps. First, we derive conditions under which the conversational equilibrium is sustainable given the secret has been disclosed. We then study the disclosure of the secret as a signaling game in any given t. Finally, we derive conditions under which the signaling game in this period t is reached. Thus, we determine when disclosure of the secret takes place in equilibrium.

Note that Proposition 1 describes the communication incentives for the non-secret holder (A_0) for this game with a secret: Not having any secret to disclose, A_0 continues if condition (6) holds true and, if $\theta > 0$, stops whenever it expects B to stop the conversation in the next period.

4.1 Conversation After Disclosure

Denote by $\tilde{\tau}$ the period in which secret holder A_1 discloses the secret during the conversation (*ex-ante*) and suppose the secret has been disclosed by A_1, so that $t > \tilde{\tau}$. Agent i's payoffs are denoted by a function $U_i(s_t|\tilde{\tau})$, $i = A, B$, of its action $s_t \in \mathscr{A}_t = \mathscr{B}_t = \{C, S\}$.

First, let agent A move in t. As before, under a conversational equilibrium for agent A's payoffs when it continues we assume that agent B always continues. In that case, both agents have access to the same number of ideas, so they both expect the product-market profits $(1-\theta)\,V(t)$. On top of this, disclosure in $\tilde{\tau}$ allows agent A to extract a constant fraction $\sigma(\tilde{\tau})$ of B's product market profits. Thus, A's payoffs when it continues in t are

$$U_A(C|\tilde{\tau}) = (1+\sigma(\tilde{\tau}))\,(1-\theta)\,V(t). \tag{8}$$

Agent A's payoffs when it stops in t are

$$U_A(S|\tilde{\tau}) \;\;=\;\; (1-\theta)\,v(t) + \theta\,[v(t) - v(t-1)] + \sigma(\tilde{\tau})\,(1-\theta)\,v(t-1). \tag{9}$$

Disclosure allows A to extract a share of B's product-market profits $(1-\theta)\,v(t-1)$. Note that since the number of ideas is not symmetric (i.e., $n_A = t$ whereas $n_B = t-1$) agent A has an advantage $v(t) - v(t-1)$ in the competitive segment of its market.

Agent A prefers to continue in t if $U_A(C|\tilde{\tau}) \geq U_A(S|\tilde{\tau})$ or

$$(1+\sigma(\tilde{\tau}))\,\frac{V(t) - v(t-1)}{v(t) - v(t-1)} \geq \frac{1}{1-\theta}. \tag{10}$$

Because $\sigma(\tau) \geq 0$ for $\tau \geq 1$, this condition is less restrictive than condition (6).

Agent B's payoffs when it continues in t under a conversational equilibrium are

$$U_B(C|\tilde{\tau}) = (1-\sigma(\tilde{\tau}))\,(1-\theta)\,V(t). \tag{11}$$

Its payoffs when it stops in t are

$$U_B(S|\tilde{\tau}) = (1 - \sigma(\tilde{\tau}))\left[v(t) - \theta v(t-1)\right]. \tag{12}$$

Agent B prefers to continue in t if $U_B(C|\tilde{\tau}) \geq U_B(S|\tilde{\tau})$ or

$$\frac{V(t) - v(t-1)}{v(t) - v(t-1)} \geq \frac{1}{1-\theta}. \tag{13}$$

This condition is equivalent to condition (6) in the scenario without a secret. Because (6) is at least as restrictive as A's condition in (10), and (6) and (13) are the same, B's condition (13) is binding. As a result, if condition (6) holds for all $t > \tilde{\tau}$, both agents will always continue conversation after disclosure of the secret until a new idea fails to arrive.

PROPOSITION 2 (Post-Disclosure Communication)**.** *If the conversational equilibrium is sustainable in the scenario without a secret then it is sustainable in the scenario with a secret after the secret has been disclosed.*

The intuition for this result is clear. Once the secret has been revealed and $\sigma(\tilde{\tau})$ determined, it is in the agents' best interest to maximize the continuation payoffs by contributing to the process as long as possible. This is because agent A receives a fraction $\frac{1+\sigma(\tilde{\tau})}{2} > 0$ of the total benefits of continuing the conversation. Moreover, if condition (6) holds, there are no gains for B from stopping the process.

In the next sections, we will show that agent B's expectations of the secret compromise the sustainability of the conversation, because the threat of a secret induces agent B to want to preemptively stop for fear of excessive rent seeking by A. Then Proposition 2 implies that the existence of the secret and its disclosure renders the conversational equilibrium (weakly) more sustainable than in the presence of asymmetric information about the secret. Our working assumption in what follows is that after the secret is disclosed the conversational equilibrium is sustainable with condition (6) satisfied.

4.2 Disclosure of the Secret

We now illustrate that conversation before disclosure of the secret and the disclosure of the secret are characterized by a conflict of interest between the two agents: A secret holder aspires to disclose the secret as late as possible. Agent B on the other hand prefers early disclosure to late disclosure as the negative payoff effects from a secret are stronger the later the secret is revealed. Indeed, not having the secret revealed, given its beliefs that agent A holds a secret, agent B may stop the conversation in order to avoid excessive extraction of its product-market profits. This may in return induce a secret holder to disclose the secret earlier than aspired.

In a setting in which agent A is never constrained by agent B's continuation decision, a secret holder will seek to disclose only after the end of the conversation. In this case the timing of such *ex-post* disclosure coincides with the final period of the conversation which we denote by $\bar{t}$. Alternatively, disclosure may take place during the conversation in $\tilde{\tau} \in T_A$. A necessary condition for such *ex-ante* disclosure is that agent B's pre-disclosure communication condition is violated.

In the sequel, at the beginning of any period t the secret has not yet been revealed and agent A types are indexed by $h = 1, 0$. Agent i's payoffs in t are a function $U_i(s_t|\tau)$, $i = A_h, B$, of its action $s_t \in \mathscr{A}_t$ if $t \in T_A$ or $s_t \in \mathscr{B}_t$ if $t \in T_B$.

4.2.1 Aspired Disclosure

Consider the case in which agent B does not constrain a secret holder A_1's decision. That means B continues in all t as in the conversational equilibrium. This allows us to determine the period τ^a for which it is individually optimal for a secret holder A_1 to disclose when it is not constrained by agent B's communication incentives. We will refer to this disclosure date τ^a as *aspired disclosure*. As we show below, the secret holder will always seek to delay disclosure until the conversation ends. This is an immediate implication from $\sigma(\tau)$ increasing in τ.

Suppose agent A_1 aspires to disclose in $\tilde{\tau}$. Its payoffs in t when it continues in t and all

$t' > t$, except $t = \tilde{\tau}$ when it discloses, and when B continues in all $t' > t$, are

$$U_{A_1}(C|\tilde{\tau}) = (1-\theta)\left[V(t) + P(t|\tilde{\tau})\right] \tag{14}$$

with

$$P(t|\tilde{\tau}) \;=\; \sum_{k=0}^{\tilde{\tau}-t-1} p^k\,(1-p)\,v(t+k)\sigma(t+1+k) + p^{\tilde{\tau}-t}\sigma(\tilde{\tau})V(\tilde{\tau}). \tag{15}$$

This $P(t|\tilde{\tau})$ is the portion a secret holder can extract from B's expected product-market profits. Conversation reaches $\tilde{\tau}$ with probability $p^{\tilde{\tau}-t}$; the associated continuation payoff the secret holder can extract is $\sigma(\tilde{\tau})V(\tilde{\tau})$. If conversation does not reach $\tilde{\tau}$, then the secret holder discloses in the terminal period $\bar{t}$. In this case what the secret holder extracts is evaluated at the terminal period of the conversation. We show in Lemma 1 that $P(t|\tilde{\tau})$ is increasing in $\tilde{\tau}$.

The secret holder's payoffs from disclosing in t are

$$U_{A_1}(D|t) = (1-\theta)\left[V(t) + P(t|t)\right]. \tag{16}$$

When A_1 decides to continue in t and disclose in its next decision period, $\tilde{\tau} = t+2$, if that period is reached, then its payoffs are

$$U_{A_1}(C|t+2) = (1-\theta)\left[V(t) + P(t|t+2)\right], \tag{17}$$

which is larger than the payoffs from disclosing in t. Finally, agent A_1's payoffs when it stops in t are

$$U_{A_1}(S|t) = v(t) + \left[(1-\theta)\,\sigma(t) - \theta\right]v(t-1), \tag{18}$$

which is equivalent to equation (9) when $\tilde{\tau} = t$.

Lemma 1 describes a secret holder A_1's best response when agent B always continues. We show that A_1 will never want to stop the conversation and delay disclosure of the secret as long as possible.

LEMMA 1. *Let condition (6) be satisfied and let B continue in all t. Agent A_1's aspired disclosure date is $\tau^a = \infty$. It will continue in all t until a new idea fails to arrive and discloses the secret ex post after conversation ends.*

The latest disclosure date possible is when the process has come to an end because a new idea has failed to arrive.[12]

4.2.2 Constrained Disclosure

Agent A being able to anticipate that B continues in all t (as in the derivation of *aspired disclosure* in Lemma 1) is not necessarily a reasonable assumption. Indeed, agent B may decide to preemptively terminate the conversation to limit the fraction of its product-market profits that agent A can extract. This decision comes with a tradeoff: continuing the conversation by sharing a new idea increases the value of conversation and agent B's product-market profits, at the cost of a higher fraction $\sigma(\cdot)$ of its profits that agent A can extract. Similarly, stopping the conversation limits this rent extraction, but comes at the cost of unrealized future values of conversation.

To formalize the problem of a secret holder constrained by B's continuation decision, let π_t denote B's beliefs in $t \in T_B$ about agent A's type, where $\pi_t = Pr(A = A_1|\Omega_t)$ and Ω_t denotes the history of all actions taken in all periods $t' < t$. Suppose B anticipates a secret holder A_1 to disclose the secret in $\tilde{\tau} \geq t$. Then B's payoffs from continuing in t under a conversational equilibrium are

$$U_B(C|\tilde{\tau}) = (1-\theta)\left[V(t) - \pi_t P(t|\tilde{\tau})\right]. \tag{19}$$

[12] The expected disclosure date is equal to the expected duration of the conversation, $\mathbb{E}\tau^a = 1 + \sum_{k=0}^{\infty} p^k (1-p)\, k = \frac{1}{1-p}$.

If agent B stops in t so that A_1 discloses (*ex post*) in t, then B's payoffs are

$$U_B(S|t) = (1 - \pi_t \sigma(t)) [v(t) - \theta v(t-1)] . \tag{20}$$

The following lemma describes agent B's best response when it anticipates a secret holder A_1 to disclose the secret in $\tilde{\tau} \in T_A$ and to continue in all other $t \in T_A \setminus \{\tilde{\tau}\}$.

LEMMA 2. *Let condition (6) be satisfied and let agent B anticipate a secret holder A_1's ex-ante disclosure in $\tilde{\tau}$. Agent B continues in $t < \tilde{\tau}$ if, and only if,*

$$\pi_t \le \bar{\pi}_t(\tilde{\tau}) \equiv \frac{(1-\theta)V(t) - [v(t) - \theta v(t-1)]}{(1-\theta)\, P(t|\tilde{\tau}) - \sigma(t)\, [v(t) - \theta v(t-1)]}. \tag{21}$$

1. *The cutoff value $\bar{\pi}_t(\tilde{\tau})$ is strictly decreasing in $\tilde{\tau}$.*

2. *If condition (6) holds with strict inequality, then $\bar{\pi}_t(\tilde{\tau})$ is strictly positive, zero otherwise. It is strictly less than one if*

$$(1 - \sigma(t)) [v(t) - \theta v(t-1)] > (1-\theta) [V(t) - P(t|\tilde{\tau})] . \tag{22}$$

By Lemma 2, agent B is more inclined to continue the conversation in t when *(i)* its beliefs π_t that agent A holds a secret are low (so that $\pi_t \le \bar{\pi}_t(\tilde{\tau})$), and *(ii)* it anticipates a secret holder A_1 to disclose early (because $\bar{\pi}_t(\tilde{\tau})$ is decreasing in $\tilde{\tau}$). When condition (6) is slack so that $\bar{\pi}_t(\tilde{\tau}) > 0$, then there exist values for the prior belief $\pi > 0$ such that agent B will never stop the conversation. Finally, observe that if (22) is violated, there is no value of $\bar{\pi}_t(\tilde{\tau})$ such that π is larger than the critical threshold in (21).

Lemma 3 describes A's best response when it anticipates agent B to continue in all periods up to $t-1$ and to stop in $t+1$.

LEMMA 3. *Suppose period t is reached. Let condition (6) be satisfied and let condition (21) be violated so that agent B stops in $t+1$ if $s_t = C$.*

1. *The non-secret holder* A_0 *stops in* t *if* $\theta > 0$. *For* $\theta = 0$, A_0 *is indifferent between stopping and continuing in* t.

2. *The secret holder* A_1 *discloses in* t *if, and only if,*

$$\frac{(1+\sigma(t))\,V(t) - v(t)}{\sigma(t+1)\left[p\left[v(t+1) - \theta v(t)\right] + (1-p)\,(1-\theta)\,v(t)\right]} \geq \frac{1}{1-\theta}. \tag{23}$$

Otherwise, the secret holder continues in t.

For a secret holder it is never optimal to stop in t. Whether or not it continues or discloses depends on how its tradeoff is resolved: Continuing in t jeopardizes future conversation since B stops in $t+1$, but it allows A_1 to delay disclosure of the secret until $t+1$, which implies a larger fraction $\sigma(t+1)$. Disclosing in t, on the other hand, salvages the conversation process since, given the post-disclosure communication condition (6) holds, B will continue in $t+1$ and all future periods. However, disclosing in t comes at the cost of lower rent extraction as $\sigma(t) < \sigma(t+1)$.

For the sequel we assume that condition (23) holds true. This means that for the secret holder it is more important to continue the conversation than concealing the secret and extracting higher rents in $t+1$. We provide the equilibrium results associated with condition (23) being violated in Appendix B.

Combining our findings from Lemmata 1, 2, and 3 for the agents' best responses gives rise to two distinct scenarios, in the first of which condition (21) is satisfied in $t+1$ so that B continues in $t+1$ when A continues in t. Here, the unique pure-strategy PBE of the signaling game played in this t is a *pooling equilibrium* in which both agent A types continue the conversation in t and B continues in $t+1$. The second case is the one in which condition (21) is violated for $t+1$ so that B stops if A continues in t. The unique pure-strategy PBE is a *separating equilibrium* in which the secret holder discloses its secret in t, the non-secret holder A_0 stops conversation, and agent B continues in $t+1$ when the secret holder discloses. Note that for both scenarios period t has been reached without disclosure as a result of both agents continuing in all $t' < t$. We return to this in Proposition 6.

DEFINITION 3 (Pure-Strategy Perfect Bayesian Equilibrium (PBE)). *Let* (s^1_t, s^0_t) *with* $s^h_t \in \mathscr{A}_t$ *be agent A's pure strategy profile, with* $h = 1, 0$*; let* $\left(s^C_{t+1}, s^D_{t+1}\right)$ *with* $s^{s_t}_{t+1} \in \mathscr{B}_{t+1}$ *be agent B's pure-strategy profile, and let* $\left(\pi^C_{t+1}, \pi^D_{t+1}\right)$ *with* $\pi^{s_t}_{t+1} \equiv Pr(A_1|s_t, \Omega_{t-1}) \in [0, 1]$ *be agent B's beliefs in its information sets. A perfect Bayesian equilibrium (PBE) in pure strategies is denoted by* $\{(s^1_t, s^0_t), (s^C_{t+1}, s^D_{t+1}); (\pi^C_{t+1}, \pi^D_{t+1})\}$.

PROPOSITION 3 (Pure-Strategy PBE). *Let conditions* (6) *and* (23) *be satisfied.*

1. *If B's prior beliefs are low,* $\pi \leq \bar{\pi}_{t+1}(\tau^a)$*, the game of conversation with secrets has a unique pure-strategy PBE. This pooling equilibrium is*

$$\{(C, C), (C, C); (\pi^C_{t+1} = \pi, \pi^D_{t+1} = 1)\}. \tag{PE}$$

2. *If B's prior beliefs are high,* $\pi > \bar{\pi}_{t+1}(\tau^a)$*, the game of conversation with secrets has a unique pure-strategy PBE. This separating equilibrium is*

$$\{(D, S), (S, C); (\pi^C_{t+1} > \bar{\pi}_{t+1}(\tau^a), \pi^D_{t+1} = 1)\}. \tag{SE}$$

LEMMA 4. *With competition,* $\theta > 0$*, the pure-strategy PBE* (PE) *and* (SE) *survive the Intuitive Criterion and D1. Without competition,* $\theta = 0$*,* (PE) *survives and* (SE) *fails to survive the criteria.*

In the pooling equilibrium (PE) for sufficiently low π, the threat of a secret holder and the associated expected negative payoff effects for B are relatively small. Agent B will continue the conversation in $t + 1$ when agent A continues in t. Therefore, the secret holder has no incentive to disclose. Both agent A types will then continue in t. For higher values of π the continuation of the conversation depends on A's decision in t. In the separating equilibrium (SE), A_1 discloses the secret in t because B would otherwise stop. A non-secret holder A_0

cannot disclose a secret it does not hold to prevent B from stopping in $t+1$ and will thus stop the conversation in t to gain from the product-market advantage it will have at this point.[13]

Given that t has been reached, the expected joint payoffs from the pooling equilibrium (PE) when both agents continue in all t are

$$W^{PE} = 2\,(1-\theta)\,V(1). \tag{24}$$

For the separating equilibrium (SE), let $t = \tau^*$ denote the period in which the secret holder discloses and the non-secret agent A_0 holder stops the conversation. The expected joint payoffs from the separating equilibrium are then equal to

$$\begin{aligned} W^{SE} \;&=\; 2\pi\,(1-\theta)\,V(1) + \\ &\quad (1-\pi)\left[2\,(1-\theta)\sum_{k=0}^{\tau^*-1} p^k\,(1-p)\,v(1+k) + p^{\tau^*}\left[v(\tau^*) - \theta v(\tau^*-1)\right]\right]. \end{aligned} \tag{25}$$

In Proposition 4 we present a mixed-strategy PBE (*hybrid equilibrium*) for the scenario in which the agents do not compete, $\theta = 0$, and the separating equilibrium (SE) when condition (21) is violated does not survive the refinements.[14]

DEFINITION 4 (Mixed-Strategy Perfect Bayesian Equilibrium (PBE))**.** *Let* $\alpha_h^{s_t} = Pr(s_t^h)$ *denote the probability agent* A_h *assigns to action* $s_t^h \in \mathscr{A}_t$*. Then* $((\alpha_1^C, \alpha_1^D, \alpha_1^S), (\alpha_0^C, \alpha_0^S))$ *is agent* A*'s mixed strategy profile. Let* $\beta_{s_t}^{s_{t+1}} = Pr(s_{t+1}|s_t)$ *denote the probability agent* B *assigns to action* $s_{t+1} \in \mathscr{B}_{t+1}$ *when agent* A *plays* s_t *in* t*. Then* $((\beta_C^C, \beta_C^S), (\beta_D^C, \beta_D^S))$ *is agent* B*'s mixed strategy profile. A perfect Bayesian equilibrium in mixed strategies (hybrid equilibrium) is denoted by* $\{((\alpha_1^C, \alpha_1^D, \alpha_1^S), (\alpha_0^C, \alpha_0^S)), ((\beta_C^C, \beta_C^S), (\beta_D^C, \beta_D^S)); (\pi_{t+1}^C, \pi_{t+1}^D)\}$.

[13] In Appendix B, we derive a pure-strategy equilibrium for the case when prior beliefs are sufficiently large and condition (23) is violated. In this alternative separating equilibrium, a secret holder agent A type continues and a non-secret holder agent A stops in t when anticipating agent B stopping in $t+1$. We do not further focus on this equilibrium because we are interested in the conditions under which a secret holder is willing to voluntarily relinquish its private information during a conversation. Our welfare implications of secrets do no qualitatively differ.

[14] There exist also mixed-strategy PBE for $\theta > 0$. Because for this scenario with competition the separating equilibrium (SE) survives the equilibrium refinements, we do not present these mixed-strategy equilibria for the sake of brevity.

PROPOSITION 4 (Mixed-Strategy PBE). *Let conditions* (6) *and* (23) *be satisfied and* $\theta = 0$*. If B's prior beliefs are high so that condition* (21) *is violated but less than one, there exists a mixed-strategy PBE*

$$\left\{((\alpha_1^*, 1-\alpha_1^*, 0), (1, 0), ((\beta^*, 1-\beta^*), (1, 0)); (\pi_{t+1}^C > \bar{\pi}_{t+1}(\tau^a), \pi_{t+1}^D = 1)\right\} \qquad \text{(HE)}$$

with $0 < \alpha_1^* < 1$*,* $0 < \beta^* < 1$*, and*

$$\pi_{t+1}^C = \frac{\pi\alpha_1^*}{\pi\alpha_1^* + (1-\pi)}.$$

LEMMA 5. *The mixed-strategy PBE* (HE) *survives the Intuitive Criterion and D1.*

Without competition, the non-secret holder agent A_0 is indifferent between continue and stop (see Lemma 3) if agent B terminates the conversation in $t+1$, but strictly prefers continue to stop if agent B continues with strictly positive probability. While a pooling equilibrium in which both agent A types continue is not feasible (because condition (21) is violated), a situation in which the secret holder can seek to delay disclosure by continuing with strictly positive probability, $\alpha_1^* > 0$, is an equilibrium outcome. In this *hybrid equilibrium*, agent B responds by continuing with strictly positive probability, $\beta^* > 0$, to render the secret holder indifferent between continue and disclose, and to induce the non-secret holder agent A_0 to continue with certainty.

Because for $\theta = 0$ the separating equilibrium (SE) in Proposition 3 does not survive the refinements, this hybrid equilibrium is the only surviving equilibrium when $\theta = 0$. Therefore, without competition and with condition (21) violated, there cannot be a perfect Bayesian equilibrium in which the secret holder discloses with certainty, and the non-secret holder A_0 stops with strictly positive probability.

4.2.3 Discussion of the Results for the Signaling Game

We discuss the results for the signaling game given that periods t and $t+1$ in which the game is played are reached, and provide conditions under which this is indeed true in Proposition 6 below.

Both agents continue in t if the prior belief π is low and the perfect Bayesian equilibrium is the *pooling equilibrium*. If this is true in all t, then the conversational equilibrium is sustainable. Thus, for sufficiently low prior beliefs about agent A's type, asymmetric information does not undermine the sustainability of the conversation. The expected joint payoffs from the conversation, W^{PE}, in equation (24) are equal to the benchmark payoffs, W, in equation (7).

As π rises above the critical threshold in a given $t+1$, the pure-strategy perfect Bayesian equilibrium is the *separating equilibrium* and calls for the disclosure of the secret in order for the conversation to continue. There are two immediate implications: First, the secret holder relinquishes private information without the obligation to do so. This allows for the conversation to continue and presents a positive effect on the sustainability of the conversation. However, if agent A does not hold a secret, the conversation breaks down and this breakdown gives rise to an inefficient outcome. We can quantify this effect by comparing the expected value of the conversation in the benchmark case without a secret, W, in equation (7) to the payoffs under the separating equilibrium (SE), W^{SE}, in equation (25). We obtain

$$\begin{aligned} W - W^{SE} &= p^{\tau^*}\left[2\,(1-\theta)\sum_{k=0}^{\infty} p^k\,(1-\theta)\,v(\tau^*+k) - [v(\tau^*) - \theta v(\tau^*-1)]\right] \\ &= p^{\tau^*}\left[2\,(1-\theta)\,V(\tau^*) - [v(\tau^*) - \theta v(\tau^*-1)]\right] > 0. \end{aligned} \tag{26}$$

This expression is strictly positive because $(1-\theta)\,V(\tau^*) \geq v(\tau^*) - \theta v(\tau^*-1)$ by condition (6) and $V(\tau^*) > 0$. Such an inefficiency is standard in models with asymmetric information and is due to the fact that the non-secret holder A_0 cannot credibly communicate the existence of the secret (i.e., its type). In Appendix B we consider the case in which both conditions (21) and (23) are violated and show that the resulting equilibrium predicts termination not only for the non-secret holder, as in the *separating equilibrium* (SE), but for both agent A types. The inefficiency caused by asymmetric information about the secret is therefore stronger in this alternative equilibrium.

The absence of competition reduces the likelihood for the breakdown of conversation because in the ensuing *hybrid equilibrium* the non-secret holder agent A_0 continues even though agent B threatens to stop with strictly positive probability after observing A continue. The reason for this is that in the absence of competition the non-secret holder A_0 is not concerned about stopping the conversation in t and obtaining a product-market advantage when it anticipates B to stop in $t+1$. However, agent B will in equilibrium preemptively terminate the conversation with strictly positive probability equal to $(1-\beta^*)\,(1-(1-\alpha_1^*)\,\pi) \in (0,1)$. The expected joint payoffs from the hybrid equilibrium, W^{HE}, lie between the payoffs from the pooling equilibrium, W^{PE}, and the separating equilibrium, W^{SE}.

This discussion gives rise to normative implications concerning the design of public policy. Clearly, agent A benefits from the presence of an institution that certifies that it is not a secret holder. We will discuss this question in greater detail in Section 5 when we apply our model to specific environments of conversations with secrets.

In Proposition 5 we present comparative statics for the critical threshold $\bar{\pi}_{t+1}(\tau^a)$ in condition (21) that determines the type of equilibrium outcome.

PROPOSITION 5. *Condition* (21) *is less restrictive and the pooling equilibrium* (PE) *more likely supported for more effective conversation processes (higher p) and for a lower degree of competition (lower θ).*

A pooling equilibrium with a sustainable conversation is more likely to arise when the process of conversation is effective with higher values of p. As the effectiveness of the conversation increases, the gains from continuing are higher and the payoffs from stopping are unaffected. More effective conversations are thus more likely to be sustainable although they leave more room for opportunistic *ex-post* disclosure.

Furthermore, a pooling equilibrium with a sustainable conversation is more likely to arise with low degrees of competition. In this environment agent B is less concerned about the consequences of a secret and condition (21) is satisfied for a larger range of prior beliefs π. This illustrates that competition has a monotonic effect on conversation. For very high degrees of product-market competition the conversational equilibrium can never be sustained as condition (6) is always violated when $\theta = 1$. As competition softens enough to render condition (6) satisfied, conversation can be initiated and is more likely to be sustainable in a pooling equilibrium.

However, while less competition reduces the chance of a breakdown of conversation, the absence of competition with $\theta = 0$ does not necessarily eliminate it. If the critical value $\bar{\pi}_{t+1}(\tau^a)$ in Lemma 2 is strictly less than one for some $t + 1$, then there is a range of prior beliefs π that render condition (21) violated and induce agent B to stop with strictly positive probability in the *hybrid equilibrium* (HE). In Proposition 1, without competition the conversational equilibrium is always sustainable when there is no secret, a result that now fails to hold when secrets introduce an additional source of asymmetric information as agent B may preemptively terminate the process.

Lower effectiveness of the conversation process (lower p) and a higher degree of competition θ imply that the pooling equilibrium (PE) is less likely to arise and the conversation is less likely to be sustainable. If lower p and higher θ render condition (21) violated but condition (23) remains satisfied, the results in Propositions 3 and 4 apply. For the case in which lower p and higher θ render *both* conditions (21) and (23) violated, we show in Appendix B that the resulting equilibrium predicts termination with strictly positive probability for not only one but both agent A types.

4.3 Conversation Before Equilibrium Disclosure

In Propositions 3 and 4 we provide the equilibria of the signaling game played by A and B in any given t and $t + 1$. It remains to be shown under which conditions this period t is reached in the conversation. An immediate implication from the pooling equilibrium (PE) is that if π is low enough, the conversational equilibrium can be sustained and disclosure is always *ex post*. However, if π is above the critical threshold $\bar{\pi}_{t+1}(\tau^a)$ for some $t+1$, i.e., if condition (21) is violated at $t+1$, then the equilibrium behavior of A_1 and A_0 in t is as in the separating equilibrium (SE) or hybrid equilibrium (HE). Can we conclude that *ex-ante* disclosure is in $t = \tau^*$ or later at equilibrium of the entire game? Could disclosure happen before? To answer this question, we need to study the game played by A and B in all t' preceding t.

In $t-2$ and $t-1$ the decisions of A and B will depend on the continuation payoffs under the equilibrium played in t. In particular, agent B in $t-1$ compares the payoffs from continuing with the payoffs from stopping in $t-1$ where in the former case it faces a secret holder that discloses in t with probability π_{t-1}. When B's beliefs fall below a critical threshold, it will not stop the conversation and the signaling game in period t is reached. Otherwise, B threatens to stop the conversation if it observes continuation in $t-2$ and a signaling game is played between A and B in stages $t-2$. If, as an outcome of this latter signaling game, a separating equilibrium analogous to (SE) arises, then A_1 discloses and A_0 stops in $t-2$, implying that the timing of *ex-ante* disclosure is no later than $t-2$.

Consider an environment with competition, $\theta > 0$. A sufficient condition for agent B to continue in all $t' \leq \tau^* - 1$ is that it is more inclined to continue when it anticipates (SE) be played in $t = \tau^*$ than when it anticipates the pooling equilibrium (PE) be played in all periods. This condition is

$$\pi\left[P(t'|\tau^a) - P(t'|\tau^*)\right] \geq (1-\pi)\, p^{\tau^*-t'-1}\left[V(\tau^*-1) - v(\tau^*-1)\right]. \tag{27}$$

Intuitively, agent B's gains when A_1 discloses in τ^* (as in the separating equilibrium (SE)) instead of τ^a (as in the pooling equilibrium (PE)), discounted by the probability π that $A = A_1$, must be at least as large as the costs that agent B incurs when the conversation stops in τ^* instead of continuing in all future periods (under (PE)), discounted by the probability $(1-\pi)\, p^{\tau^*-t'-1}$ that $A = A_0$ and stage $\tau^* - 1$ is reached.

Now consider an environment without competition, $\theta = 0$. In the resulting hybrid equilibrium the secret holder discloses and continues with strictly positive probabilities. Irrespective of the agents' behavior in $t+2$, $t+3$, and further rounds, agent B will expect a secret holder to disclose in some period $\tau^e \in (\tau^*, \tau^a)$. A sufficient condition for agent B to continue in all $t' \leq \tau^* - 1$ is that it is more inclined to continue when it anticipates (HE) be played in $t = \tau^*$ than when it anticipates the pooling equilibrium (PE) be played in all periods. This condition is

$$\pi \left[P(t'|\tau^a) - P(t'|\tau^e)\right] \geq 0 \tag{28}$$

which holds by $\tau^e < \tau^a$.

The following Proposition 6 summarizes the results for the sustainability of the conversational equilibrium and the timing of equilibrium disclosure.

PROPOSITION 6. *Define* $\pi^{\inf} \equiv \inf \bar{\pi}_{t+1}(\tau^a)$. *Let condition (6) be satisfied for all* t.

1. *For* $\pi \leq \pi^{\inf}$, *the conversational equilibrium with ex-post disclosure is sustainable.*

2. *For* $\pi > \pi^{\inf}$, *there is some* $\pi > \bar{\pi}_{t+1}(\tau^a)$. *Let* $t = \tau^*$ *be the smallest* $t \in T_A$ *such that* $\pi > \bar{\pi}_{\tau^*+1}(\tau^a)$. *If condition (27) is satisfied and* $\theta > 0$ *is sufficiently small, then the signaling game with the separating equilibrium (SE) is reachable and ex-ante disclosure is in* τ^*.

3. *For* $\pi > \pi^{\inf}$, *the signaling game with equilibrium (HE) when* $\theta = 0$ *is reachable and ex-ante disclosure is in* τ^* *or later.*

[Table 1 about here.]

In Table 1 we summarize the equilibrium results of the model of conversations with secrets when condition (23) is satisfied. Recall that if the condition is violated the resulting equilibrium renders conversation unsustainable for both agent A types.[15]

[15] Also, we do not focus on the mixed-strategy equilibrium for $\theta > 0$ since its qualitative results are identical to those of the pure-strategy separating equilibrium (SE).

The first implication is that asymmetric information has no effect on the sustainability of the conversational equilibrium when agent B's prior beliefs about the secret are low. In this case, disclosure of the secret is *ex post*. Private information affects only the distribution of the value of conversation, but the picture changes when prior beliefs increase. The nature of the results then depends on product-market competition. With competition, i.e., if $\theta > 0$, and given the conditions in Proposition 6, the conversational equilibrium can be sustained only if agent A is a secret holder and *ex-ante* disclosure is in τ^*. Otherwise the conversation stops in τ^*. Without competition, $\theta = 0$, the conversational equilibrium can be sustained with certainty only if agent A is not a secret holder. If instead it holds a secret, the conversation is terminated with strictly positive probability. Disclosure is *ex ante* in τ^* or later. If $\pi^{\inf} < 1$, then there is always a sufficiently high π such that these two latter cases arise.

Finally, for $\theta > 0$ disclosure is immediate and $\tau^* = 1$ (or immediate with strictly positive probability for $\theta = 0$) if prior beliefs are sufficiently high, $\pi > \bar{\pi}_2(\tau^a) \geq \pi^{\inf}$, with $\tau^a = \infty$.[16] Such a case always exists if this critical threshold $\bar{\pi}_2(\tilde{\tau})$ evaluated at $\tilde{\tau} = \tau^a$ in Lemma 2 is strictly less than one. By condition (22) this holds true if

$$(1 - \sigma(2)) [v(2) - \theta v(1)] > (1 - \theta) [V(2) - P(2|\infty)] \tag{29}$$

for $\theta \geq 0$. Immediate disclosure implies that a conversational equilibrium is sustainable only if agent A is a secret holder. A non-secret holder agent A_0 type will in this equilibrium not initiate the conversation.

[Table 2 about here.]

In Table 2 we present a numerical example with functional forms $v(t) = 1 - \alpha^t$ and $\sigma(t) = 1 - \beta^t$ and $\alpha = \beta = 9/10$. Moreover, the probability of a new idea arriving is $p = 1/2$. Given this parameterization, condition (6) is satisfied for $\theta \leq 9/20$. For the example in the table we consider the cases of no competition with $\theta = 0$ and competition with $\theta = 1/10$ and $\theta = 4/10$.

[16] In particular, if $\pi = 1 > \bar{\pi}_2(\tau^a) \geq \pi^{\inf}$ then disclosure is immediate.

Agent B's prior beliefs are either relatively low with $\pi = 1/4$ or high with $\pi = 3/4$ and $\pi = 1$. Condition (23) is satisfied for $t = \tau^*$ for all cases where $\pi > \pi^{\text{inf}}$.

Note that for the separating equilibrium for $\pi = 3/4 > \pi^{\text{inf}}$ and $\theta = 1/10$ with $\tau^* = 3$ the sufficient conditions in Proposition 6 are satisfied and the conversation indeed reaches $t = \tau^* = 3$. For the separating equilibrium for $\pi = 1/4$ and $\theta = 4/10$ we obtain $\tau^* = 3$. However, because agent B will stop in $t = 2$ anticipating that agent A discloses in $t = 3$,[17] this period $t = \tau^* = 3$ is not reached. The secret holder then discloses immediately in $t = 1$. At last, for $\pi = 1$ disclosure is delayed for low degrees of competition because condition (29) is violated but condition (27) is satisfied. For high degrees of competition condition (29) holds and disclosure is immediate.

4.4 Known Secrets

In our analysis the focus so far has been on the effect a secret has on the sustainability of conversation. We have assumed that the disclosure of the existence of the secret implies the disclosure of the terms of the secret. In the sequel we relax this assumption to study how asymmetric information about the content of the secret affects the sustainability of the conversation.

For this we assume the existence of a secret is common knowledge, however, its terms have not yet been disclosed.[18] While agent B's prior beliefs are $\pi = 1$, it does not have knowledge about the terms of the secret and can therefore not take precautionary measures to protect itself against agent A's *ex-post* opportunism. This means that the fraction σ agent A can extract from agent B's product-market profits is increasing in τ. The separation of the terms of the secret from the existence of the secret—keeping the former constant but varying the latter—allows us to derive the effect of private information about agent A's type on the sustainability of conversation. By comparing the expected joint payoffs from the equilibria for the full model (W^{PE}, W^{SE}, and W^{HE}) with the joint expected payoffs from the equilibrium in this intermediate case of common knowledge (denoted by W^{CK}) we can quantify the inefficiency

[17] More specifically, condition (A19) in the proof of Proposition 6 is violated.

[18] The case in which it is common knowledge that no secret exists is the scenario analyzed in Section 3.

arising from asymmetric information in a model of conversation with secrets. The results in Proposition 7 follow from Propositions 3 and 4 for $\pi = 1$.

PROPOSITION 7. *Let conditions (6) and (23) be satisfied. Suppose the existence of a secret is common knowledge but its terms are not. If condition (29) holds then equilibrium disclosure is immediate, $\tau^* = 1$, and delayed otherwise. Conversation is sustainable in all $t \geq 1$.*

The expected joint payoffs from the equilibrium for the case of common knowledge in Proposition 7 are equal to $W^{CK} = W^{SE}|_{\pi=1} = W$. This holds true for both the case of immediate disclosure (with $\bar{\pi}_2(\tau^a) < 1$) and delayed disclosure (with $\bar{\pi}_2(\tau^a) \geq 1$). Observe that these payoffs are the same as the payoffs from conversation without a secret in Section 3. *Ex-post* opportunism on the part of the secret holder A by means of function σ has an effect on welfare (measured by expected joint payoffs) only if it is accompanied by B's uncertainty about agent A's type. With common knowledge of the type (and the existence of the secret) has a distributive effect only.

We can quantify the welfare losses arising from asymmetric information about agent A's type by comparing the expected payoffs from the baseline model with the expected payoffs from the scenario with common knowledge. First observe that asymmetric information has no effect on welfare when agent B's prior beliefs are sufficiently small ($\pi < \pi^{\inf}$) and the equilibrium is the pooling equilibrium (PE) in which conversation is sustainable for both agent A types. In this case, $W^{PE} = W = W^{CK}$. However, when agent B's beliefs are higher and the equilibrium is not pooling, implying that the conversation is terminated prematurely with strictly positive probability, then the welfare losses caused by asymmetric information are equal to $W^{CK} - W^{SE} = W - W^{SE} > 0$ for $\theta > 0$ and $W^{CK} - W^{HE} = W - W^{HE} > 0$ for $\theta = 0$. This is the extra milage due to asymmetric information in a model of conversation.

5 Applications

5.1 Industry Standard Development

Industry standards are developed and implemented for various reasons: They facilitate the interoperability of products and increase their value to customers (Scotchmer, 2004:289ff; Shapiro and Varian, 1998), reduce production costs (Thompson, 1954), and improve the rate of diffusion of new technologies (Rysman and Simcoe, 2008). Moreover, standardization eliminates miscoordination among producers (Farrell and Klemperer, 2007:2026f). Our model captures the salient features of industry standard development and allows us to study how product-market competition among committee members and patent protection of some of the components of a standard undermine the workings of standard-setting organizations (SSOs). The results provide novel insights into the functioning of standard setting (modeled as an exchange of *ideas*) and the decision to disclose standard-essential patents (*secrets*).

As Farrell and Saloner (1988:250) point out, "[standard-setting] committees often identify and promote compromises." Moreover, "participants are often engineers who share information and view the committee as a design process, and pursue an 'ideal technology'." We provide a theory that addresses these functions of SSOs and captures standard setting in an environment characterized by genuine need to develop a standardized technology. This is the case in SSOs such as ETSI or JEDEC, where firms repeatedly meet to develop a standard by exchanging ideas in a cooperative environment.[19]

The process is initiated when a member proposes to work on a standard and, upon the manifestation of interest of other members, a committee is formed.[20] Standard setting then works through a sequence of meetings in which firms, represented by their engineers, exchange *ideas* for standard improvement, discussing the technologies to be incorporated into a given standard and striving for better technological outcomes.

[19]Also, Simcoe (2012b:312f) describes the early IETF as an SSO that "creates and maintains" standards, with early members being academic and government researchers.

[20]Updegrove (1993) provides interesting evidence on the formation of standard-setting working groups. Also, DeLacey, Herman, Kiron, and Lerner (2006) discuss the process of mobile Internet standards development by the committees in the Institute of Electrical and Electronics Engineers (IEEE).

Strategic tensions often undermine the work of standard-setting committees. Typically, participating firms are competitors, with inherent conflicting interests when it comes to the exchange of proposals for standard improvement. Moreover, it can be difficult for other participants to identify whether any of the technologies considered for inclusion in the standard are patent protected.[21] The existence of a patent can therefore be viewed as a *secret*, i.e., a piece of private information, and a committee member can at best form beliefs about its existence. The difficulty arises for at least two reasons: First, identifying a patent that is relevant to the development of a specific standard imposes significant search costs (DOJ-FTC, 2007:43; Bessen and Meurer, 2008:51,53-4). In this spirit, 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 standard-setting effort." Second, patent applications are frequently pending while the underlying technologies are considered for inclusion, and patent applications are not published for at least 18 months after the filing (Johnson and Popp, 2003; Aoki and Spiegel, 2009).

When the patent holder manages to get his patented technology included, it can hope for a future stream of licensing revenue. This might induce patent holders to conceal the existence of standard-essential patents to other members of the standard-setting committee. Chiao, Lerner, and Tirole (2007) provide results that confirm that disclosure of patents may be used strategically. Late disclosure may equip the patent holder with bargaining leverage over prospective users. Such leverage is the result of the technology users' *lock in* (Shapiro and Varian, 1998; Farrell and Klemperer, 2007) and arises when firms rely on the standard (yet to be published and adopted), make irreversible or standard-specific investments,[22] and manufacture final products based on the present state of the standard proposal. The empirical findings in Layne-Farrar (2011) suggest that—in absence of a clear rule—firms postpone the disclosure of patents until the end of the standard-setting process, i.e., *ex post*, after the publication of a

[21]Empirical research shows that the strategic effects are likely to be amplified if the standard incorporates intellectual property. See, for instance, Weiss and Sirbu (1990).

[22]Such types of lock-in are, e.g., contractual commitments, durable goods purchases and capital equipment, training, use of specialized suppliers, or customer loyalty programs (Shapiro and Varian, 1998:116-130).

standard version.[23] Such conduct by means of *ex-post* disclosure is often referred to as patent ambush, a form of patent holdup at the core of many high profile legal disputes[24] and greatly debated in the law and economics literature.[25]

5.1.1 Patent Disclosure and the Process of Standard Development

In our model, a patent holder can follow two strategies: It either (1) decides to disclose the patent *ex ante*, before the process ends, and thus foregoes parts of its bargaining leverage while salvaging the standard-setting process, or (2) it chooses to disclose the patent *ex post* and thus fully exploits its bargaining leverage. We assume that *ex-post* disclosure comes without direct costs (e.g., through disclosure rules or reputation concerns) and provide conditions under which the patent holder will decide to disclose *ex ante* even in the absence of such costs.

If a patent holder expects the other participant to always contribute to the process with a new idea, then it is in the patent holder's best interest to always share ideas but disclose the patent as late as possible. However, if a patent holder cannot rely on the other participant to always contribute to the process, then in equilibrium the disclosure decision is constrained and the patent holder may be inclined to disclose *ex ante*. In Propositions 3 and 4 we provide the conditions under which *ex-ante* disclosure is observable in equilibrium. A patent holder will disclose *ex ante* when the other firm expects to pay a license fee (i.e., it expects to face a patent holder) with sufficiently high prior probability were the process to continue without disclosure. Absent disclosure of a patent, the firm stops the standardization process to limit the patent holder's bargaining leverage. This in return induces the patent holder to disclose the patent *before* the other firm exercises its "threat" in order to salvage the process. When the members of the standard-setting organization are product-market competitors, then the

[23] Layne-Farrar (2011) studies the timing of more than 14,000 patent declarations (the means by which patents are disclosed) in the European Telecommunication Standards Institute (ETSI) as of December 2010. The dataset contains declarations to important mobile telecom related ETSI projects, such as GPRS, GSM, UMTS, and WCDMA.

[24] 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)*), or *Broadcom Corp. v. Qualcomm Inc., 501 F.3d 297 (3d Cir. 2007)*, plaintiffs contended that patentees failed to comply with the SSO's disclosure rules.

[25] See Farrell, Hayes, Shapiro, and Sullivan (2007) or Lemley and Shapiro (2007) among many others.

resulting equilibrium is a *separating equilibrium* (SE), as characterized in Proposition 3, in which a patent holder reveals private information *ex ante* and a non-patent holder stops the process. When the members do not compete in the product market, the resulting equilibrium is a *hybrid equilibrium* (HE), as characterized in Proposition 4, in which the patent holder discloses *ex ante* with strictly positive probability.

The patent holder can rely on the other participant to always contribute to the process if the latter's prior beliefs about facing a patent holder are sufficiently low. In that case, the standard-setting process ends only when a new idea fails to arrive and the patent is disclosed *ex post*. The resulting equilibrium is a *pooling equilibrium* (PE) as characterized in Proposition 3 and is consistent with the empirical findings in Layne-Farrar (2011).

Proposition 5 provides guidance as to when *ex-post* disclosure is more likely to arise. We show that the condition supporting the *pooling equilibrium* is more likely to be satisfied for lower degrees of competition (lower values of θ) and for more effective conversation processes (higher values of the idea arrival parameter p). Intuitively, soft product-market competition reduces the incentives to stop the conversation, thus lowering the patent holder's risk of a premature end of the process by a rival's threat to stop. At the same time, for more lively standard-setting committees, those in which the flow of ideas for improvement is more prolific and the expected payoffs from the process are higher, rival participants are less likely to stop the process in order not to forego the increased benefits of standardization. As a result, more effective committees and those with lower product-market competition of its participants are more likely to experience *ex-post* disclosure and are thus more vulnerable to *ex-post* rent extraction by strategic patent holders.

5.1.2 Policy Implications for Standard Development

The normative implications of our analysis are concerned with institutions that avoid the inefficiency caused by "early" termination of the process that arises in the separating equilibrium when a rival participant faces a non-patent holder. We discuss three possible solutions.

License Commitments. Under licensing commitments the patent holder promises to license a standard-essential patent at a pre-defined or maximum license fee or royalty rate,[26] irrespective of the timing of disclosure. The most common policy is to require licensing on *Reasonable and Non-Discriminatory (RAND)* terms.[27] We argue that such RAND commitments (or license commitments in more general) can solve the inefficiency associated with the *separating equilibrium* (SE).

Suppose an SSO adopts a license commitment policy and suppose the royalty rate under such a commitment is σ^R so that $\sigma(\tau) \leq \sigma^R$. Let the conditions in Proposition 6 be satisfied and the standard-setting process reach the signaling game in τ^*. Then, an optimal pre-committed royalty rate cap is $\sigma^R \leq \sigma(\tau^*)$. To see this, recall that, as we showed in Lemma 2, a rival's "threat" to stop the process absent disclosure arises when later disclosure results in higher license fees or royalty rates. If $\sigma^R \leq \sigma(\tau^*)$, the maximum royalty rate is not higher than the rate that would induce the rival participant to stop in $\tau^* + 1$ absent disclosure in τ^*. Therefore, for all $t > \tau^*$, the rival participant firm B has no incentive to stop the process in case the patent has not been disclosed, and a non-patent holder A_0 will not stop the process in τ^* but continue. As for the patent holder, it is indifferent between disclosing in τ^* and disclosing later, since it cannot increase the royalty rate by disclosing later. To summarize, a license commitment $\sigma^R \leq \sigma(\tau^*)$ solves the inefficiency from early process termination in the separating equilibrium.

Therefore, our model suggests that, for standard-setting to produce high-quality standards, the royalty rates associated with RAND commitments should not be too high. More specifically, a *reasonable* royalty of $\sigma^R > \sigma(\tau^*)$ will not be binding and thus not solve the inefficiency arising in the separating equilibrium. Of course, the positive effect of lower σ^R on the sustainability of the standard-setting process must be balanced with the possibly negative effects a

[26] Two examples of pre-defined license fee are provided by Simcoe (2012a:69,n27): The World Wide Web Consortium (W3C) requires royalty-free licensing whereas the HDMI Consortium sets royalties at $0.15 per unit sold. A maximum-license-fee policy is followed by VITA whose rules state that "working group members must declare the maximum royalty rate" they will charge for a license. See October 30, 2006, letter from Thomas O. Barnett (U.S. Department of Justice) to Robert Skitol, available at http://www.justice.gov/atr/public/busreview/219380.pdf.

[27] Swanson and Baumol (2005), Farrell, Hayes, Shapiro, and Sullivan (2007), or Layne-Farrar, Padilla, and Schmalensee (2007), among others. See Contreras (2013a:n20) for evidence of the use of RAND commitments.

lower *reasonable* royalty (or maximum royalty) has on patent holders' incentives to participate in standard-setting committees (see, e.g., Layne-Farrar, Llobet, and Padilla, 2012) and their incentives to innovate (see, e.g., Ganglmair, Froeb, and Werden, 2012).

Implied Waiver. A court stipulated *implied waiver* renders one's patents waived if the SSO has disclosure rules in place that require all participants to disclose all standard-essential patents but a patent has not been disclosed by the time the standard-setting process comes to an end.[28] This policy institution is motivated by the outcomes of court decisions in important cases of (alleged) patent ambush.[29] We provide a simple rationale for its introduction in the context of our model.

With an *implied waiver* rule in place, the patent holder runs the risk of not being able to disclose in time before the process ends if it delays disclosure, rendering its patent unenforceable. The waiver thus introduces a cost of *ex post* disclosure. As a result, even when the standard-setting process is not constrained by a rival's "threat" to stop, the patent holder is more inclined to disclose *ex ante*.[30] This effect of the waiver is consistent with the findings in Layne-Farrar (2011), who documents that the introduction of a clear disclosure rule—clarifying firms' obligation to declare (i.e., disclose) relevant patents before the publication of a standard—triggers earlier patent declarations (i.e., *ex-ante* disclosure).

In a standard-setting environment in which, without the waiver, the equilibrium is a *pooling equilibrium*, the introduction of a waiver will result in earlier disclosure (and lower license fees) but will not affect the sustainability and duration of the standard-setting process. The process continues until a new idea fails to arrive, independent of the waiver. In an environment in which the equilibrium is a *separating equilibrium*, whether or not the waiver affects the duration of the

[28] For a discussion of disclosure rules as a solution to the problem of patent hold-up see Simcoe (2012a:66-9), for a recent survey of *ex-ante* disclosure rules see Contreras (2013b). For a more general discussion of the effect of disclosure laws see Grossman and Hart (1980).

[29] For instance, the U.S. Court of Appeals for the Federal Circuit found in *Qualcomm Inc. v. Broadcom Corp., 2007-1545, 2008-1162 (Fed. Cir. 12-1-2008)* that "it was within the district court's authority ... to determine that Qualcomm's misconduct falls within the doctrine of waiver." The conclusion was an "un-enforceability remedy limited in scope to any [standard]-compliant products." See Hovenkamp, Janis, Lemley, and Leslie (2010:35-58ff) for a discussion of this and related cases.

[30] Our results under the waiver are a direct implication of the analysis developed above. We provide the formal analysis in Appendix C.

standard-setting process depends on when the patent holder would otherwise disclose. Suppose disclosure in the scenario with the waiver is before disclosure in the scenario without. Then the signaling game is never played along the equilibrium path. Therefore, with the implied waiver rule, both firms continue the conversation until a new idea fails to arrive, whereas the conversation stops without waiver when a rival participant faces a non-patent holder. Hence, the introduction of a waiver is desirable insofar as it avoids an inefficient termination of the conversation.

Certificates. The last solution we discuss is borrowed from the literature on asymmetric information that suggests quality certification to overcome the lemons problem (e.g. Viscusi, 1978). In the context of our model, quality certification is implemented by way of the patent office certifying that the firm requesting the certificate has not applied for a patent that might be essential to the standard. Because patent applications are not in the public domain for at least 18 months after initial filing, such a certificate eliminates the uncertainty over the existence of pending patents. If the inefficiency associated with the *separating equilibrium* (SE) arises from a non-patent holder A_0 not being able to credibly communicate that it does not hold a patent application then such a certificate can remedy this problem as it can convince the rival participant that it faces no expropriation threat. In circumstances in which the patent office holds superior information about standard-setting participants—which is the case with patent applications—the provision of the certificate is desirable.

A number of features of standard-setting processes are not captured by our setting. First, the economics literature has viewed standard setting as a means to achieve *ex-post* coordination on one out of a number of competing technologies and thus to generate network effects. A prominent approach is to model standard setting as a war of attrition and the delay in standard adoption as a costly byproduct (e.g., Farrell and Saloner, 1988; Farrell and Simcoe, 2012). We present a model in which the benefits of collaborative standard setting arise through *ex-ante* cooperation and complementarities in idea production (see, e.g., Farrell and Saloner, 1988:250). In our model a longer conversation allows firms to achieve a better technological outcome.

We believe that the introduction of costly delay (see also Simcoe, 2012b) would not affect the qualitative nature of our results.[31]

Second, in our setting the delay of disclosure, and the resulting stronger scope for holdup, does not reduce the total value generated by the process, but only implies a different redistribution of the same value. This outcome can be rationalized by the use of a two-part tariffs scheme in which the patent holder sets the linear component to achieve bilateral efficiency, whereas the value of the fixed component depends on the bargaining power of the patent holder (Tarantino, 2012).

5.2 Joint Ventures and Business Ventures

Joint ventures are cooperative agreements to jointly develop a business idea in a (potentially) competitive environment (Kogut, 1989:196). In a research joint venture, more specifically, firms share technological knowledge while often remaining competitors in the product market (e.g., d'Aspremont and Jacquemin, 1988; Hernán, Marín, and Siotis, 2003). Our model can be applied in this context to answer the question of how sustainable a (research) joint venture is (i.e., how much information partners share) in the presence of asymmetric information, and to what extent product-market competition and research spillovers (through parameter p) affect the sustainability.[32] We view R&D as the process of sharing information rather than a single reduced-form parameter of R&D effort to which firms can cooperatively commit at a pre-competition stage (e.g., Suzumura, 1992).

The basic concept of a joint venture is captured by our model. Often joint ventures (or business ventures) are started when an entrepreneur A shares with a colleague B an idea for a novel initiative and develop through the exchange of further *ideas* for improvements or combinations of complementary resources (Doz and Hamel, 1998). An improvement of the

[31] If delay is costly (e.g., when a technology is not brought to market on time and loses market potential) then there is an optimal finite end date of conversation, say $\bar{\tau}$. In such a scenario, a conversational equilibrium is one in which the conversation reaches this optimal end date. A secret will compromise the sustainability of the conversation if the equilibrium disclosure date is before the optimal end of conversation, i.e., if $\tau^* < \bar{\tau}$.

[32] For the literature on research joint ventures and the effect of product-market competition and spillovers see also, e.g., Choi (1993) and Combs (1993).

quality of the venture by exchanging more ideas increases the total value of the project. Each partner is interested in maximizing the size of the pie to be shared while at the same time trying to capture as large a fraction of that pie as possible.

Furthermore, suppose this entrepreneur A has control over some of the required resources through, e.g., exclusive supply contracts for an essential input. This means that, if the entrepreneur decides to keep this control over essential resources a *secret*, the two partners design the joint venture under asymmetric information. For instance, part of the joint venture is that partner B invests in a production facility that requires the use of an essential input which partner A controls. Through this, A can *ex post* extract side payments from B. If that secret were to be disclosed early on, then firm B would not be subject to *ex-post* opportunism in the terms of the partnership or could insist on a business design that allows for substitute inputs. Recall from the equilibrium results for the conversation game with secrets that we would expect to see more *ex-post* opportunism (in a pooling equilibrium) in partnerships with weak product-market competition and high potential of the joint venture (high p) reflected by a high complementarity of resources or R&D spillovers.

Just like a patent in the earlier example, an exclusive supply contract is *ex-ante* verifiable. The owner of such a contract can reveal it to its partner. An entrepreneur without such a contract, however, cannot reveal a contract that does not exist. The implication for the equilibrium outcome of this business venture is an inefficient termination of the venture (for sufficiently high prior beliefs) by the entrepreneur without the exclusive contract. By Proposition 5, the separating equilibrium that gives rise to inefficient termination is more likely to arise with fiercer competition and lower potential of the partnership. This is consistent with theoretical results in the literature. Pérez-Castrillo and Sandonís (1996) survey the literature on research joint ventures and conclude that with high spillovers (high value of p) firms prefer cooperative R&D. They further argue that in research joint ventures partners have little incentive to share information when they are simultaneously competitors in other markets.

Furthermore, the management literature provides some empirical results that are consistent with our model findings. Park and Ungson (1997) find evidence that the sustainability of joint ventures is negatively affected when partners compete, i.e., when their product markets overlap (as proxy for our model parameter θ).[33] Moreover, in Li (1995) and Hennart, Kim, and Zeng (1998) the sustainability of joint ventures is positively affected by industry growth and higher value of cooperation (as proxies for our model parameter p).

6 Concluding Remarks

In this paper, we study how the sustainability of a conversation between competing agents is affected by the existence of a secret. We present a dynamic model of conversation as exchange of *ideas* (Stein, 2008) in which one agent is endowed with a piece of private information that provides for *ex-post* bargaining leverage and affects the distribution of final payoffs. We study the impact this *secret* has on the sustainability of the conversation and analyze the secret holder's decision to disclose the secret and relinquish its private information.

We show that even if there are no explicit rules requiring disclosure and the secret holder can disclose after the end of the conversation, thus fully exploiting its bargaining leverage, it may nonetheless choose to disclose before the end of the process (*ex-ante* disclosure). This happens when the secret holder A_1 cannot rely on its rival B to always share new ideas and continue the conversation. Disclosing the secret then prevents preemptive termination by agent B who would otherwise stop the conversation to limit the secret holder's *ex-post* bargaining leverage and rent extraction. Because a non-secret holder A_0 cannot credibly communicate it does not hold a secret (due to the *ex-ante* verifiability of the secret), when it anticipates agent B to terminate the conversation, A_0 stops the conversation to obtain a product-market advantage. Private information about how the returns of a conversation are shared therefore negatively affects the success (and sustainability) of conversation. We show that this inefficiency is more likely to arise the fiercer the competition between the agents and the slower the flow of new ideas.

[33] Related to this is the example discussed in von Hippel (1987). There, firms competing for an important government contract in the aerospace industry report not to trade information with rivals.

We apply our model to two specific contexts. We model the process of *industry standard development* as one of *ex-ante* cooperation in the development of a new technology (Farrell and Saloner, 1988:250) rather than *ex-post* coordination of existing technologies. This enables us to provide novel insights into the functioning of standard setting (exchange of ideas for improvement of a technology) and the decision to disclose standard-essential patents (secrets). We also discuss the effectiveness of *ex-ante license commitments* (e.g., *RAND* commitments), *implied waivers* of patent rights, and *certificates* as remedies of the inefficiency caused by private information. The second example we discuss applies our model to business ventures and the their sustainability when a secret exclusive contract over the supply of an essential input provides the owner of the contract with *ex-post* leverage to extract side payments from its partner.

A Proofs

Proof of Proposition 1

Proof. Let p and θ be such that condition (6) holds for all t, then neither agent has an incentive to deviate from the conversation strategy (i.e., they always continue) for any t.

If condition (6) is violated for some t, so that agent i stops in t, then agent $-i$ stops in $t-1$. Agent $-i$ in $t-1$ anticipates that if it continues in $t-1$,, with probability $1-p$ agent i will not observe a new idea in t, and agent $-i$'s payoffs are $(1-\theta)\,v(t-1)$. With probability p, a new idea arrives which agent i will not share and agent $-i$'s payoffs are $(1-\theta)\,v(t-1)$. Therefore, agent $-i$'s expected payoffs from continuing in $t-1$ when i stops in t are $(1-\theta)\,v(t-1)$. Its payoffs from stopping in $t-1$ are instead $(1-\theta)\,v(t-1)+\theta\,[v(t-1)-v(t-2)] = v(t-1)-\theta v(t-2)$. Agent $-i$ therefore stops for any $\theta > 0$. By the same argument, agent i stops in $t-2$. Continuing in this fashion, agent A stops in $t = 1$. Conversation is thus not initiated if condition (6) is violated for *some* t.

To show that the condition is less restrictive for higher values of p, observe that $V(t)$ is increasing in p: The derivative for $V(t)$ with respect to p is

$$\frac{\partial V(t)}{\partial p} = \sum_{k=0}^{\infty} p^k \left(\frac{k(1-p)}{p} - 1\right) v(t+k),$$

which, after some manipulation, can be rewritten as

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

for all $p \in (0,1)$. As $V(t)$ increases in p, the LHS of condition (6) increases in p and the condition becomes less restrictive. To show that the condition is less restrictive for lower values of θ, note that the RHS is increasing in θ.

Finally, to show that condition (6) always holds for $\theta = 0$, we show that the LHS is strictly larger than unity. For that, $V(t) > v(t)$. Since

$$\begin{aligned} V(t) - v(t) &= \sum_{k=0}^{\infty} p^k (1-p)\, v(t+k) - \sum_{k=0}^{\infty} p^k (1-p)\, v(t) \\ &= \sum_{k=0}^{\infty} p^k (1-p) \left[v(t+k) - v(t) \right] > 0 \end{aligned}$$

holds for all t and $p \in (0,1)$, condition (6) holds for all t if $\theta = 0$. Q.E.D.

Proof of Proposition 2

Proof. Agent B's condition (13) is identical to both agents' condition (6) in the case without secret (or in the case with a secret when $\tau = 1$). Because $\sigma(\tilde{\tau}) \geq 0$ for all $\tilde{\tau} \geq 1$, (13) is at least as restrictive as (10). If (13) holds for all $t \geq \tilde{\tau}$, then (10) holds for all $t \geq \tilde{\tau}$. Hence, if (6) for the case without a secret holds, then both (10) and (13) for the case with a revealed secret hold as well. Q.E.D.

Proof of Lemma 1

Proof. We first construct $P(t|\tilde{\tau})$. This payment from B to A is equal to B's product market profits times σ. Suppose firm B continues in t, and let $\tilde{\tau} = t + 1$. We obtain

$$\begin{aligned} P(t|t+1) &= (1-p)\, \sigma(t+1) v(t) + p\,(1-p)\, \sigma(t+1) v(t+1) + \\ & \quad p^2 (1-p)\, \sigma(t+1) v(t+2) + p^3 (1-p)\, \sigma(t+1) v(t+3) + \ldots \\ &= \sigma(t+1) V(t). \end{aligned} \tag{A1}$$

This $P(t|t+1)$ is the expected value of conversation to agent B multiplied by σ taking into account that σ is capped at any $t+1$ when agent A discloses.

Now, suppose that A does not disclose before $\tilde{\tau} = t + 3$, i.e., it will disclose whenever the process comes to end before $t+3$, or in $t+3$ when this stage is reached. The expected payments to A are

$$\begin{aligned} P(t|t+3) &= (1-p)\,\sigma(t+1)v(t) + p\,(1-p)\,\sigma(t+2)v(t+1) + \\ &\quad p^2\,(1-p)\,\sigma(t+3)v(t+2) + p^3\,(1-p)\,\sigma(t+3)v(t+3) + \\ &\quad p^4\,(1-p)\,\sigma(t+3)v(t+4) + \dots \\ &= \sum_{k=0}^{2} p^k\,(1-p)\,\sigma(t+1+k)v(t+k) + p^3\sigma(t+3)V(t+3). \end{aligned}$$

The expression in (15) is derived analogously for general $\tilde{\tau}$.

To show that $P(t|\tilde{\tau})$ is increasing in $\tilde{\tau}$, we compare $P(t|\tilde{\tau})$ with $P(t|\tilde{\tau}+\omega)$ and show that $P(t|\tilde{\tau}+\omega) > P(t|\tilde{\tau})$ for all $\omega \geq 1$. From equation (15),

$$P(t|\tilde{\tau}+\omega) = \sum_{k=0}^{\tilde{\tau}+\omega-t-1} p^k\,(1-p)\,v(t+k)\sigma(t+1+k) + p^{\tilde{\tau}+\omega-t}\sigma(\tilde{\tau}+\omega)V(\tilde{\tau}+\omega). \tag{A2}$$

After some manipulation we obtain

$$\begin{aligned} P(t|\tilde{\tau}+\omega) - P(t|\tilde{\tau}) &= p^{\tilde{\tau}-t}\sum_{k=0}^{\omega-1} p^k(1-p)v(\tilde{\tau}+k)\,[\sigma(\tilde{\tau}+1+k)-\sigma(\tilde{\tau})] + \\ &\quad p^{\tilde{\tau}+\omega-t}\,[\sigma(\tilde{\tau}+\omega)-\sigma(\tilde{\tau})]\,V(\tilde{\tau}+\omega) > 0, \end{aligned}$$

which is positive because $\sigma(\tilde{\tau})$ is increasing in $\tilde{\tau}$.

The result that later disclosure with payoffs $U_{A_1}(C|t+2)$ is always better than immediate disclosure with payoffs $U_{A_1}(C|t)$ follows from $P(t|\tilde{\tau})$ increasing in $\tilde{\tau}$ and a direct comparison of the two payoff expressions. Hence, the aspired disclosure date is $\tau^a = \infty$ and the secret holder's payoffs are $U_{A_1}(C|\infty) = (1-\theta)\,[V(t) + P(t|\infty)]$. Moreover, if $U_{A_1}(C|\infty) > U_{A_1}(S|t)$ for all t, then it is never optimal for a secret holder to stop in t. Indeed,

$$U_{A_1}(C|\infty) = (1-\theta)\,[V(t)+P(t|\infty)] > v(t) + \theta v(t-1) + (1-\theta)\,\sigma(t)v(t-1) = U_A(S|t)$$

since

$$\begin{aligned} P(t|\infty) - \sigma(t)v(t) &= \sum_{k=0}^{\infty} p^k (1-p)\, \sigma(t+k+1)v(t+k) - \sum_{k=0}^{\infty} p^k (1-p)\, \sigma(t)v(t) \\ &= \sum_{k=0}^{\infty} p^k (1-p) \left[\sigma(t+k+1)v(t+k) - \sigma(t)v(t)\right] > 0. \end{aligned}$$

and condition (6) ensures that $(1-\theta)\, V(t) \geq v(t) + \theta v(t-1)$. Q.E.D.

Proof of Lemma 2

Proof. Condition (21) follows directly from the comparison of (19) and (20).

1. The cutoff value is strictly decreasing in $\tilde{\tau}$ because $P(t|\tilde{\tau})$ is strictly increasing in $\tilde{\tau}$ (Lemma 1).

2. If condition (6) holds with strict equality, then the numerator in (21) is equal to zero. Moreover, the denominator is strictly positive if

$$\frac{P(t|\tilde{\tau}) - \sigma(t)v(t-1)}{\sigma(t)\left[v(t) - v(t-1)\right]} > \frac{1}{1-\theta}. \tag{A3}$$

   Because by equation (A1)

$$\frac{P(t|\tilde{\tau}) - \sigma(t)v(t-1)}{\sigma(t)\left[v(t) - v(t-1)\right]} > \frac{V(t) - v(t-1)}{v(t) - v(t-1)} \iff P(t|\tilde{\tau}) > \sigma(t)V(t) = P(t|t), \tag{A4}$$

   condition (6) is more constraining than (A3), i.e., if (6) holds with strict equality, (A3) is slack and the denominator in (21) is strictly positive so that $\bar{\pi}_t(\tilde{\tau}) = 0$. If (6) is slack and the numerator in (21) strictly positive, (A3) holds and the denominator in (21) is positive so that $\bar{\pi}_t(\tilde{\tau}) > 0$.

   The cutoff value is strictly less than one if the denominator in (21) is larger than the numerator. After some manipulation, condition (22) is obtained. Q.E.D.

Proof of Lemma 3

Proof. First note that for t to have been reached without the secret disclosed, all agents must have continued in all $t' < t$.

1. As shown in the proof of Proposition 1, the non-secret holder A_0's payoffs from continuing in t when B stops in $t+1$ are $(1-\theta)\,v(t)$. Its payoffs from stopping in t are $(1-\theta)\,v(t) + \theta\,[v(t) - v(t-1)] = v(t) - \theta v(t-1)$ (equation (5)). When $\theta > 0$, A_0 strictly prefers stop to continue; when $\theta = 0$, A_0 is indifferent.

2. For the secret holder A_1, the payoffs from stopping in t, $U_{A_1}(S|t)$, are in equation (18). By Proposition 2, and condition (6) satisfied, B continues in $t+1$ if A_1 discloses in t. Moreover, both agents then continue in all $t' > t+1$ until a new idea fails to arrive. The secret holder's payoffs from disclosing in t are thus equal to $U_{A_1}(D|t)$ in equation (16). Observe that stopping is dominated by disclosing if $U_{A_1}(D|t) \geq U_{A_1}(S|t)$ or

$$(1+\sigma(t))\,\frac{V(t) - v(t-t)}{v(t) - v(t-1)} \geq \frac{1}{1-\theta}, \tag{A5}$$

   using $P(t|t) = \sigma(t)V(t)$. Because (6) holds and $\sigma(t) > 0$ unless for $t = 1$ when $\sigma(1) = 0$ (so that (6) and (A5) are equivalent), this condition always holds. We therefore focus on A_1's decision to either disclose in t or continue in t. If the secret holder continues in t, then by condition (21) in Lemma 2 being violated in $t+1$, agent B will stop in $t+1$ and the conversation ends. Secret holder A_1 then discloses the secret after conversation ends in $t+1$. Its payoffs from continuing in t when B stops in $t+1$, $\bar{U}_{A_1}(C|t+1)$, are

$$\begin{aligned}
\bar{U}_{A_1}(C|t+1) &= (1-p)\,[(1-\theta)\,v(t) + \sigma(t+1)\,(1-\theta)\,v(t)] + \\
&\quad\; p\,[(1-\theta)\,v(t) + \sigma(t+1)\,(v(t+1) - \theta v(t))] \qquad \text{(A6)} \\
&= (1-\theta)\,v(t) + \sigma(t+1)\,[p\,(v(t+1) - \theta v(t)) + (1-p)(1-\theta)v(t)]\,.
\end{aligned}$$

The secret holder will disclose in t if $U_{A_1}(D|t) \geq \bar{U}_{A_1}(C|t+1)$, or

$$\frac{(1+\sigma(t))\,V(t)-v(t)}{\sigma(t+1)\,[p\,[v(t+1)-\theta v(t)]+(1-p)(1-\theta)v(t)]} \geq \frac{1}{1-\theta}$$

which is condition (23). Q.E.D.

Proof of Proposition 3

Proof. We derive perfect Bayesian equilibria (PBE) in pure strategies of the continuation game played in t and $t+1$ by agent A_h types $h = 1, 0$ and agent B. Note that the secret has not yet been disclosed. In order for t to be reached (without disclosure) both agent A types must have continued in all $t' < t$, and B has not had a chance to update its beliefs, so that $\pi_{t'} = \pi$ for all $t' < t$. More specifically, $\pi^C_{t-1} = \pi$.

1. (PE): If agent B continues in $t+1$, then by Propositions 1 and 2, both agent A types continue in t for all θ and $s^1_t = s^0_t = C$. In $t+1$, agent B will not be able to update its beliefs and $\pi^C_{t+1} = \pi^C_{t-1} = \pi$. Condition (21) can be rewritten as $\pi \leq \bar{\pi}_{t+1}(\tilde{\tau})$ for some $\tilde{\tau} \in T_A$. If condition (21) holds for $\tilde{\tau} = \tau^a = \infty$, $\pi \leq \bar{\pi}_{t+1}(\infty)$, then by Lemma 1 the secret holder will delay disclosure until after the conversation ends, $\tau^a = \infty$, and both agents continue in all t and $t+1$ since condition (21) holds for $\tilde{\tau} = \tau^a$.

   Neither agent A type has an incentive to deviate: If, out-of-equilibrium, A_1 chooses D instead of C, then $\pi^D_{t+1} = 1$ (by virtue of credible disclosure of its type). Because (6) is satisfied, by Proposition 2 agent B continues once the secret has been disclosed, $s^D_t = C$. But then A_1 prefers C to D. If either agent chooses S instead of C then the conversation stops. Since on the equilibrium path agent B continues, both agent A types prefer C to S (by (6) satisfied).

   To show that (PE) is the unique pure-strategy PBE, we consider the following five remaining strategy profiles (s^1_t, s^0_t) with $s^1_t, s^0_t \in \mathscr{A}_t$ for agents A_1 and A_0: (D,S), (D,C), (C,S), (S,S), and (S,C). Given profiles (D,S), (D,C), and (S,C) agent A_1 deviates by playing $s_t^1 = C$ which, by (21) satisfied, implies $s_{t+1}^C = C$ and disclosure is as in Lemma 1. Likewise, given profile (S, S) agent A_1 deviates, e.g., by playing $s_t^1 = D$ to induce B to continue. Finally, given profile (C, S) agent A_0 deviates by playing $s_t^0 = C$ to induce $s_{t+1}^C = C$. Hence, if (21) is satisfied, the pooling equilibrium (PE) is the unique pure-strategy PBE.

2. (SE): Suppose condition (21) with $\tilde{\tau} = \tau^a$ is violated for some $t+1$, B stops in $t+1$ if agent A continues in t so that $s_{t+1}^C = S$. If (23) is satisfied a secret holder A_1, who anticipates B to stop in $t+1$ when $s_t = C$, strictly prefers disclose to continue, $s_t^1 = D$. In this case, agent B continues by Proposition 2 so that $s_{t+1}^D = C$. A non-secret holder A_0 who anticipates $s_{t+1}^C = S$ weakly prefers stop to continue in t so that $s_t^0 = S$ for $\theta \geq 0$ and strictly prefers stop to continue for $\theta > 0$. After $s_t^0 = S$ the game ends and no information set for B is reached in $t+1$. For both agent A types, agent B does not need to update its beliefs on the equilibrium path using Bayes' rule because its information set is a singleton (agent A_1 discloses), or the game has ended (agent A_0 stops). The equilibrium action profile for agent A in period t is $(s_t^{1*}, s_t^{0*}) = (D, S)$. If, out-of-equilibrium, B observes agent A to continue, then at least one of the types must have deviated. The out-of-equilibrium beliefs that support the separating equilibrium are $\pi_{t+1}^C > \bar{\pi}_{t+1}(\tau^a)$. Given these posterior beliefs, by condition (21) in Lemma 2 agent B will stop in $t+1$ if agent A continues in t. Because A_1 then prefers disclose to continue and A_0 prefers stop to continue, no agent A type will deviate from $(s_t^{1*}, s_t^{0*}) = (D, S)$.

To show that (SE) is the unique pure-strategy PBE, we consider the following five remaining strategy profiles: (C, C), (D, C), (C, S), (S, S), and (S, C). Note that by Lemma 3, $s_t^1 = S$ is dominated by $s_t^1 = D$, and $s_t^1 = C$ (inducing $s_{t+1}^C = S$) is dominated by $s_t^1 = D$ because (23) is satisfied. Hence, agent A_1 will deviate from profiles (C, C), (C, S), (S, S), and (S, C). Given (D, C), A_0 deviates by playing $s_t^0 = S$, as $s_{t+1}^C = S$ when (21) is violated. The payoffs for A_0 when it plays $s_t^0 = C$ (and B stops in $t+1$) are $(1-\theta)\, v(t)$ which is (weakly for $\theta = 0$) smaller than the payoffs for $s_t^0 = S$, $v(t) - \theta v(t-1)$, and A_0

is better off playing $s_t^0 = S$. Hence, if (21) is violated and (23) is satisfied, the separating equilibrium (SE) is the unique pure-strategy PBE. Q.E.D.

Proof of Lemma 4

Proof. We show that both equilibria satisfy the *Intuitive Criterion* and *D1* for $\theta > 0$, (PE) survives for $\theta = 0$, and (SE) fails to survive for $\theta = 0$.

First, note that there is no information set for agent B following $s_t^h = S$, $h = 1, 0$. We therefore do not have to consider an out-of-equilibrium action S by agent A. Some further notation will be helpful: Let $\tilde{\alpha}_h(s_t)$ denote the probability agent A_h assigns to action $s_t \in \mathscr{A}_t$ in the candidate equilibrium (s_t^{1*}, s_t^{0*}). Then denote by

$$\tilde{\mathscr{A}_t} = \{s_t \in \mathscr{A}_t : \tilde{\alpha}_h(s_t) = 0 \text{ for both types } h = 1, 0\} \setminus \{S\}$$

the set of out-of-equilibrium actions. Moreover, for the relevant actions $s_t \in \{C, D\}$ (the ones followed by an information set for agent B), let $\mathscr{P}(s_t)$ the set of agent A types whose action set includes s_t: $\mathscr{P}(C) = \{A_1, A_0\}$ and $\mathscr{P}(D) = \{A_1\}$. Finally, let $BR(\mathscr{P}(s_t), s_t)$ be the set of agent B's best responses to action s_t by agent A when agent A types in $\mathscr{P}(s_t)$ can take action s_t.

For the *Intuitive Criterion* (Cho and Kreps, 1987) we take two steps. *Step 1:* We determine the set of agents for which an out-of-equilibrium action $s_t \in \tilde{\mathscr{A}_t}$ is not equilibrium dominated:

$$\Theta(s_t) = \big\{A_h | U^*_{A_h}(s_t^{h*}) \leq \max_{s_{t+1} \in BR(\mathscr{P}(s_t), s_t)} U_{A_h}(s_t)\big\}, \tag{A7}$$

where $U^*_{A_h}(s_t^{h*})$ is agent A_h's payoff from the equilibrium profile $\{(s_t^{1*}, s_t^{0*}), (s_{t+1}^{D*}, s_{t+1}^{C*})\}$ and $\max_{s_{t+1} \in BR(\mathscr{P}(s_t), s_t)} U_{A_h}(s_t)$ represents the highest payoff that A_h can achieve by sending the out-of-equilibrium message $s_t \in \tilde{\mathscr{A}_t}$ in t when agent B replies with a best response $s_{t+1} \in BR(\mathscr{P}(s_t), s_t)$. *Step 2:* Once beliefs are restricted to $\Theta(s_t)$, the originally proposed equilibrium with payoff $U^*_{A_h}(s_t^{h*})$ does not survive the *Intuitive Criterion* if there is a type $A_h \in \Theta(s_t)$ and an action $s_t \in \tilde{\mathscr{A}_t}$ that improves upon the type's equilibrium payoff $U^*_{A_h}(s^{h*}_t)$, even if action s_t is responded in $t+1$ with the action providing the lowest possible payoff $\min_{s_{t+1} \in BR(\Theta(s_t), s_t)} U_{A_h}(s_t)$. The formal condition is:

$$\min_{s_{t+1} \in BR(\Theta(s_t), s_t)} U_{A_h}(s_t) > U^*_{A_h}(s^{h*}_t) \quad \text{for } A_h \in \Theta(s_t). \tag{A8}$$

If both conditions (A7) and (A8) are satisfied, the equilibrium fails to survive the *Intuitive Criterion.*

1. *Intuitive Criterion for* (PE)*:* For (PE), $\tilde{\mathscr{A}_t} = \{D\}$ and $\mathscr{P}(D) = \{A_1\}$. Because $\pi^D_{t+1} = 1$, $BR(\mathscr{P}(D), D) = \{C\}$. *Step 1:* The (highest) payoff associated with $s^1_t = D$ and $s_{t+1} = C \in BR(\mathscr{P}(D), D)$ is $U_{A_1}(D|t)$ which by Lemma 1 is lower than the equilibrium payoff, so that action $s^1_t = D$ is equilibrium dominated and (A7) is violated for A_1. Hence, no agent A type has an out-of-equilibrium action $s_t \in \tilde{\mathscr{A}_t}$ that could make it better off, $\Theta(D) = \emptyset$. (PE) survives the *Intuitive Criterion* refinement for all θ.

2. *Intuitive Criterion for* (SE)*:* For (SE), $\tilde{\mathscr{A}_t} = \{C\}$ and $\mathscr{P}(C) = \{A_1, A_0\}$. When out-of-equilibrium agent B sees $s_t = C$, then $\pi^C_{t+1} = \pi$ and the best response to C is S because (21) is violated for $\pi^C_{t+1} = \pi$, $BR(\mathscr{P}(C), C) = \{S\}$.

   Step 1: Let us consider the cases of $\theta > 0$ and $\theta = 0$ separately:

   For $\theta > 0$. The (highest) payoff associated with $s^1_t = C$ and $s_{t+1} = S \in BR(\mathscr{P}(C), C)$ is $\bar{U}_{A_1}(C|t+1)$ which is, by condition (23) satisfied, smaller than the equilibrium payoff $U_{A_1}(D|t)$ so that action $s^1_t = C$ is equilibrium dominated and condition (A7) is violated for type A_1. For A_0, the (highest) payoff associated with $s^0_t = C$ and $s_{t+1} = S \in BR(\mathscr{P}(C), C)$ is $U_{A_0}(C) = (1-\theta)\,v(t)$, which is smaller than the equilibrium payoff, $U_{A_0}(S) = v(t) - \theta v(t-1)$, so that action $s^0_t = C$ is equilibrium dominated and (A7) is violated for A_0. Hence, $\Theta(C) = \emptyset$. (SE) survives the *Intuitive Criterion* refinement for $\theta > 0$.

For $\theta = 0$. Again, condition (A7) is violated for type A_1. For A_0, the (highest) payoff associated with $s_t^0 = C$ and $s_{t+1} = S \in BR(\mathscr{P}(C), C)$ is $U_{A_0}(C) = v(t)$, which is the same as the equilibrium payoff, $U_{A_0}(S) = v(t)$, so that action $s_t^0 = C$ is *not* equilibrium dominated and (A7) is satisfied for A_0. Hence, $\Theta(C) = \{A_0\}$.

Step 2: Because $\Theta(C) = \emptyset$ if $\theta > 0$, this second step applies only to the case when $\theta = 0$. For $\Theta(C) = \{A_0\}$, $\pi_{t+1}^C = 0 < \bar{\pi}_{t+1}(\tau^a)$. This implies that condition (21) is satisfied. Agent B's best response is $s_{t+1}^C = C$ and $BR(\Theta(C), C) = \{C\}$. The (lowest) payoffs for A_0 when it plays $s_t^0 = C$ (and B plays C in $t+1$) are $V(t)$ which is larger than the equilibrium payoffs $U_{A_0}(S) = v(t)$ because $V(t) > v(t)$. Hence, condition (A8) is satisfied and (SE) does not survive the *Intuitive Criterion* refinement if $\theta = 0$.

For the *D1* criterion (Cho and Kreps, 1987), we consider a slightly stricter *Step 1.* (Both criteria coincide in *Step 2*). For *D1*, the set $\Theta(s_t)$ of potential deviators contains the one agent A type that is *more likely* to take an out-of-equilibrium action $s_t \in \tilde{\mathscr{A}_t}$. More specifically, an agent A_h, $h = 1, 0$, is *more likely* to take an out-of-equilibrium action $s_t \in \tilde{\mathscr{A}_t}$ than an agent A_{-h} if there are more best responses $s_{t+1} \in BR(\mathscr{P}(s_t), s_t)$ to s_t such that the condition in equation (A7) is satisfied. Let $R_{A_h}(s_t)$ be the set of agent B's best responses $s_{t+1} \in BR(\mathscr{P}(s_t), s_t)$ that render $A_h \in \Theta(s_t)$,

$$R_{A_h}(s_t) = \big\{ s_{t+1} | U_{A_h}^*(s_t^{h*}) \leq \max_{s_{t+1} \in BR(\mathscr{P}(s_t), s_t)} U_{A_h}(s_t) \big\}. \tag{A9}$$

Let $|R_{A_h}(s_t)|$ be the number of elements in $R_{A_h}(s_t)$. Then, the type h for which $|R_{A_h}(s_t)|$ is largest is *more likely* to take an out-of-equilibrium action and is the single element in $\Theta(s_t)$.

D1 is (weakly) more restrictive than the *Intuitive Criterion*. It refines the set of equilibria only if $\Theta(s_t)$ in (A7) for the *Intuitive Criterion* is not a singleton, i.e., contains both agent A types. If $\Theta(s_t)$ in (A7) for the *Intuitive Criterion* is a singleton (or the empty set) and the candidate equilibrium survives the *Intuitive Criterion*, it also survives *D1*.

1. *D1 for* (PE)*:* For (PE), $\tilde{\mathscr{A}_t} = \{D\}$. Because $\Theta(D) = \emptyset$ when defined for the *Intuitive Criterion*, (PE) survives *D1*.

2. *D1 for* (SE)*:* Let $\theta > 0$. For (SE), $\tilde{\mathscr{A}_t} = \{C\}$. Because $\Theta(C) = \emptyset$ when defined for the *Intuitive Criterion*, (SE) survives *D1* for $\theta > 0$. Because for $\theta = 0$, (SE) does not survive the *Intuitive Criterion*, it does not survive *D1*. Q.E.D.

Proof of Proposition 4

Proof. First, note that by condition (6), if A_1 discloses in t then B continues in $t+1$ with probability 1, $\beta_D^C = Pr(s_{t+1}^D = C|D) = 1$ and $\beta_D^S = 0$. Let then $\beta_C^C \equiv \beta$ and $\beta_C^S \equiv 1 - \beta$ agent B's response to $s_t = C$. Moreover, for agent A_1 stopping is dominated by disclosing (Lemma 3) so that $\alpha_1^S = 0$. Let then $\alpha_1^C \equiv \alpha_1$ and $\alpha_1^D \equiv 1 - \alpha_1$ so that $(\alpha_1, 1 - \alpha_1, 0)$ is A_1's strategy profile. Finally, let $\alpha_0^C \equiv \alpha_0$ and $\alpha_0^S \equiv 1 - \alpha_0$ so that $(\alpha_0, 1 - \alpha_0)$ is A_0's strategy profile.

Suppose condition (21) with $\tilde{\tau} = \tau^a$ is violated for some $t+1$, B stops in $t+1$ if agent A continues with certainty in t. In this case the pooling equilibrium (PE) with $\alpha_1 = \alpha_0 = 1$ and $\pi_{t+1}^C = \pi$ cannot be sustained because $\pi_{t+1}^C = \pi > \bar{\pi}_{t+1}(\tau^a)$. Because a secret holder A_1 prefers disclose to continue (because (23) is satisfied), the separating equilibrium (SE) with $\alpha_1 = \alpha_0 = 0$ can be sustained. In addition, a hybrid equilibrium can be constructed in which A_1 randomizes between continue and disclose (so as to leave B indifferent between continue and stop) and B randomizes between continue and stop (so as to leave A_1 indifferent between continue and disclose).

In such a hybrid equilibrium, given α_1, α_0, and $\pi_{t-1} = \pi$, by Bayes' rule, agent B's posterior belief in $t+1$ is

$$\pi_{t+1} = \frac{\pi\alpha_1}{\pi\alpha_1 + (1-\pi)\,\alpha_0}. \tag{A10}$$

Because for $\alpha_0 = 0$, $\pi_{t+1} = 1$ for any α_1, the optimal strategy for A_1 is then to disclose with probability 1, as in the separating equilibrium (SE). For A_1 to play disclose and continue with strictly positive probabilities, A_0 must continue with strictly positive probability, $\alpha_0 > 0$.

Agent B with posterior beliefs π_{t+1} in (A10) is indifferent between continue and stop in $t+1$ if $U_B(C|\tau^e)$ in equation (20) (for $t+1$) is equal to $U_B(S|t)$ in equation (19) (for $t+1$). This τ^e is the expected future disclosure date, which may not be equal to the aspired disclosure date τ^a. Setting (20) equal to (19) we obtain

$$\begin{aligned} V(t+1) - \pi_{t+1} P(t+1|\tau^e) &= (1 - \pi_{t+1}\sigma(t+1))\, v(t) \\ V(t+1) - v(t) &= \frac{\alpha_1 \pi}{\alpha_1 \pi + \alpha_0 (1-\pi)} \left[P(t+1|\tau^e) - \sigma(t+1) v(t) \right]. \end{aligned}$$

After some rearranging we obtain

$$[V(t+1) - v(t)] \left[\alpha_1 \pi + \alpha_0 (1-\pi) \right] = \alpha_1 \pi \left[P(t+1|\tau^e) - \sigma(t+1) v(t) \right]$$

which holds if, and only if,

$$\alpha_1 = \hat{\alpha}_1(\alpha_0) \equiv \frac{\alpha_0 (1-\pi)}{\pi} \frac{V(t+1) - v(t)}{P(t+1|\tau^e) - V(t+1) + (1 - \sigma(t+1))\, v(t)}. \tag{A11}$$

For the sufficient conditions such that $\hat{\alpha}_1 \in (0,1)$ we are as restrictive as possible and set τ^e equal to the the next possible disclosure date in the next round, hence $\tau^e = t+2$. A sufficient condition for $\hat{\alpha}_1(\alpha_0) < 1$ for all $\alpha_0 > 0$ is

$$\pi > \frac{V(t+1) - v(t)}{P(t+1|t+2) - \sigma(t+1) v(t)} = \frac{V(t+1) - v(t)}{\sigma(t+2) V(t+1) - \sigma(t+1) v(t)}.$$

Finally, $\hat{\alpha}_1(\alpha_0) > 0$ for all $\alpha_0 > 0$ if, and only if,

$$\frac{V(t+1) - v(t)}{P(t+1|t+2) - \sigma(t+1) v(t)} = \frac{V(t+1) - v(t)}{\sigma(t+2) V(t+1) - \sigma(t+1) v(t)} < 1. \tag{A12}$$

Moreover, if this condition holds, there is a range of values of $\pi < 1$ such that $\hat{\alpha}_1(\alpha_0) < 1$. The condition holds true if $\sigma(t+2)$ is sufficiently larger than $\sigma(t+1)$. In particular, if $\sigma(t+2)$ tends to one.

If $\alpha_1 = \hat{\alpha}_1(\alpha_0)$, then agent B is indifferent between continue and stop. In order for A_1 to play $0 < \hat{\alpha}_1(\alpha_0) < 1$, agent B must play β so as to make the secret holder indifferent between continue and disclose. The secret holder is indifferent in t if the payoffs from disclosing in t are equal to the expected payoffs from continuing in t, i.e., $U_{A_1}(D|t) = \beta U_{A_1}(C|\tau^e) + (1-\beta)\,\bar{U}_{A_1}(C|t+1)$ with $U_{A_1}(D|t)$ in equation (16), $U_{A_1}(C|\tau^e)$ in equation (14), and $\bar{U}_{A_1}(C|t+1)$ in equation (A6). We obtain:

$$(1+\sigma(t))\,V(t) = \beta\left[(V(t) + P(t|\tau^e)\right] + (1-\beta)\left[v(t) + \sigma(t+1)\,(pv(t+1) + (1-p)\,v(t))\right].$$

This equality holds for

$$\beta = \beta^* \equiv \frac{(1+\sigma(t))\,V(t) - \left[v(t) + \sigma(t+1)\,(pv(t+1) + (1-p)\,v(t))\right]}{V(t) + P(t|\tau^e) - \left[v(t) + \sigma(t+1)\,(pv(t+1) + (1-p)\,v(t))\right]} \tag{A13}$$

where $\beta^* < 1$ because $P(t|\tau^e) > P(t|t) = \sigma(t)V(t)$ for all $\tau^e \geq t+2$. Because the numerator of (A13) is smaller than the denominator, a sufficient condition for $\beta^* > 0$ is a positive numerator which holds true by (23) being satisfied.

At last, the non-secret holder A_0 prefers continue to stop for any $\beta > 0$,

$$\beta U_{A_0}(C) + (1-\beta)\,\bar{U}_{A_0}(C) = \beta V(t) + (1-\beta)\,v(t) > v(t) = U_{A_0}(S),$$

where $\bar{U}_{A_0}(C)$ denotes A_0 payoffs when B stops in $t+1$, and therefore plays a strategy $\alpha_0 = \alpha_0^* = 1$.

In equilibrium, $\alpha_0^* = 1$, $\alpha_1^* = \hat{\alpha}_1(1) \in (0,1)$ in equation (A11), and $\beta^* \in (0,1)$ in equation (A13). Both information sets of agent B are reached with strictly positive probability. Posterior beliefs π_{t+1}^C are given in equation (A10) and $\pi_{t+1}^D = 1$. Q.E.D.

Proof of Lemma 5

Proof. Intuitive Criterion for (HE)*:* Because α_1^* is strictly between 0 and 1, all actions $s_t \in \mathscr{A}_t$ that are followed by an information set for B are played with strictly positive probability so that $\tilde{\mathscr{A}_t} = \emptyset$. (HE) survives the *Intuitive Criterion* refinement. Because there is no out-of-equilibrium action in (HE), the hybrid equilibrium survives *D1*. Q.E.D.

Proof of Proposition 5

Proof. We proof the Proposition in two steps.

1. Condition (21), evaluated at $t+1$ as in our equilibrium analysis, is less restrictive for lower values of θ if $\bar{\pi}_{t+1}(\tau^a)$ is decreasing in θ. The derivative of $\bar{\pi}_{t+1}(\tau^a)$ with respect to θ is

$$\frac{\partial \bar{\pi}_{t+1}(\tau^a)}{\partial \theta} = -\frac{[P(t+1|\tau^a) - \sigma(t+1)V(t+1)] \cdot [v(t+1) - v(t)]}{\{(1-\theta)\, P(t+1|\tau^a) - \sigma(t+1)\,[v(t+1) - \theta v(t)]\}^2} < 0,$$

   and is negative because $P(t+1|\tilde{\tau})$ is increasing in $\tilde{\tau}$ (Lemma 1) and $\tilde{\tau} > t+1$, so that $P(t+1|\tau^a) > \sigma(t+1)V(t+1) = P(t+1|t+1)$. Hence, $\bar{\pi}_{t+1}(\tau^a)$ is decreasing in θ.

2. Condition (21) is less restrictive for higher values of p if $\bar{\pi}_{t+1}(\tau^a)$ is increasing in p. To show this, let $\Delta_V \equiv \partial V(t+1)/\partial p$ denote the change of $V(t+1)$ as a response to a marginal change of p, and let $\Delta_P \equiv \partial P(t+1|\tau^a)/\partial p$ denote the change of $P(t+1|\tau^a)$ as a response to a marginal increase in p. Then

$$\Delta_V = \sum_{k=0}^{\infty} p^k \left(\frac{k(1-p)}{p} - 1 \right) v(t+k+1) > 0$$

   and

$$\Delta_P = \sum_{k=0}^{\infty} p^k \left(\frac{k(1-p)}{p} - 1 \right) \sigma(t+k+2) v(t+k+1) > 0.$$

   Because $v(t)$ is an increasing and concave function, and $\sigma(t)$ is an increasing and concave function with range $[0,1]$, $\Delta_V > \Delta_P$. To show that $\bar{\pi}_{t+1}(\tau^a)$ is increasing in p, observe that only $V(t+1)$ in the numerator and $P(t+1|\tau^a)$ in the denominator are functions of p. Given an increase of p from p to p', the value of $V(t+1)$ increases to $V(t+1)|_{p'} = V(t+1)|_p + \Delta_V$;

the value of $P(t+1|\tau^a)$ increases to $P(t+1|\tau^a)|_{p'} = P(t+1|\tau^a)|_p + \Delta_P$. Hence, $\bar{\pi}_{t+1}(\tau^a)$ increases as p increases if

$$\bar{\pi}_{t+1}(\tau^a)|_p < \frac{(1-\theta)\,[V(t+1)|_p + \Delta_V] - [v(t+1) - \theta v(t)]}{(1-\theta)\,[P(t+1|\tau^a)|_p + \Delta_P] - \sigma(t+1)\,[v(t+1) - \theta v(t)]}.$$

After some manipulation, this condition can be rewritten as

$$\bar{\pi}_{t+1}(\tau^a)|_p = \frac{(1-\theta)\,V(t+1) - [v(t+1) - \theta v(t)]}{(1-\theta)\,P(t+1|\tau^a)|_p - \sigma(t+1)\,[v(t+1) - \theta v(t)]} < \frac{\Delta_V}{\Delta_P}. \tag{A14}$$

In Lemma 2 we show that $\bar{\pi}_{t+1}(\tau^a)$ is strictly less than one. Then, because $\Delta_V > \Delta_P$,

$$\bar{\pi}_{t+1}(\tau^a)|_p < 1 < \frac{\Delta_V}{\Delta_P},$$

and condition (A14) holds true. Hence, $\bar{\pi}_{t+1}(\tau^a)$ is increasing in p. Q.E.D.

Proof of Proposition 6

Proof. For **claim (1)**, note that if $\pi \leq \pi^{\inf} = \inf \bar{\pi}_{t+1}(\tau^a)$, then the condition for the pooling equilibrium (PE) in Proposition 3 is satisfied not only for a given $t+1$ but for *all* $t+1 \geq 2$. This implies that in any given t and $t+1$, both agent A types and agent B will continue and the conversational equilibrium is sustainable.

For claims (2) and (3) we establish the conditions under which neither agent A types nor agent B have an incentive to deviate from a continuation strategy in any stage $t' < \tau^*$ preceding the signaling game played in τ^* and τ^*+1 with the separating equilibrium (SE) in claim (2) when $\theta > 0$ and the hybrid equilibrium (HE) in claim (3) when $\theta = 0$. This means, given B continues in all $t' \leq \tau^* - 1$, we derive conditions under which both agent A types continue in all $t' \leq \tau^* - 2$; and given both agent A types continue in all $t' \leq \tau^* - 2$, we derive conditions under which agent B continues in all $t' \leq \tau^* - 1$.

Claim (2). *Secret holder A_1:* If the secret holder (disclosing in τ^* in (SE)) continues in t', it obtains expected payoffs of $(1-\theta)[V(t') + P(t'|\tau^*)]$. If it stops in t', it obtains payoffs of $v(t') - \theta v(t'-1) + \sigma(t')(1-\theta)v(t'-1)$. Thus, if B continues in all $t' \leq \tau^* - 1$, the secret holder continues in all $t' \leq \tau^* - 2$ if, and only if,

$$\frac{V(t') + P(t'|\tau^*) - (1+\sigma(t'))\,v(t'-1)}{v(t') - v(t'-1)} \geq \frac{1}{1-\theta}, \tag{A15}$$

which is always satisfied if (6) holds true in t'. To establish this, note that for $t' = \tau^*$, the condition is equivalent to condition (10) (where $\tau^* = \tilde{\tau}$) which is less restrictive than (6) for $\tau^* > 1$ and equivalent to (6) for $\tau^* = 1$. Hold t' constant, as τ^* increases, $P(t'|\tau^*)$ increases and the LHS of condition (A15) increases, rendering the condition less restrictive.

Non-secret holder A_0: If the non-secret holder (stopping in τ^* in (SE)) continues in t', it obtains expected payoffs of

$$(1-\theta)\sum_{k=0}^{\tau^*-t'-1} p^k(1-p)\,v(t'+k) + p^{\tau^*-t'}\left[v(\tau^*) - \theta v(\tau^*-1)\right].$$

If it stops in t', it obtains payoffs of $v(t') - \theta v(t'-1)$. Thus, if B continues in all $t' \leq \tau^* - 1$, the non-secret holder A_0 continues in all $t' \leq \tau^* - 2$ if, and only if,

$$(1-\theta)\sum_{k=0}^{\tau^*-t'-1} p^k(1-p)\,v(t'+k) + p^{\tau^*-t'}\left[v(\tau^*) - \theta v(\tau^*-1)\right] \geq v(t') - \theta v(t'-1). \tag{A16}$$

We first show that $\theta \to 0$ is a sufficient condition for (A16) to hold true in all $t' \leq \tau^* - 2$. To this end, we rewrite condition (A16) for $\theta \to 0$ and obtain

$$\sum_{k=0}^{\tau^*-t'-1} p^k(1-p)\,v(t'+k) + p^{\tau^*-t'}v(\tau^*) - v(t') \geq 0. \tag{A17}$$

After some manipulation, the LHS of (A17) can be rewritten as

$$\sum_{k=1}^{\tau^*-t'} p^k \left[v(t'+k) - v(t'+k-1)\right],$$

which is strictly positive since $v(t)$ is strictly increasing in t. Hence, for $\theta \to 0$, the non-secret holder A_0 continues in all $t' \leq \tau^* - 2$. Moreover, by continuity, if θ is positive but sufficiently small, condition (A16) holds true and A_0 continues in all $t' \leq \tau^* - 2$ when it anticipates B to continue in all $t' \leq \tau^* - 1$.

Agent B: For agent B we derive a sufficient condition under which B, in all periods $t' \leq \tau^* - 1$, is more inclined to continue when the equilibrium in the continuation game starting at τ^* is the separating equilibrium (SE) than in the case when the equilibrium in the continuation game in τ^* is the pooling equilibrium (PE). In other words, the idea is to obtain the condition such that the posterior beliefs' critical threshold below which B continues in all $t' \leq \tau^* - 1$ is larger when (SE) is played in τ^* than when (PE) is played in τ^*.

From Lemma 2, we know that under a conversational equilibrium in which the pooling equilibrium (PE) is played in τ^* agent B continues in t' if

$$V(t') - \pi_{t'} P(t'|\tau^a) \geq \frac{U_B(S|t')}{1-\theta} \tag{A18}$$

is satisfied, where $U_B(S|t')$ in equation (20) are B's payoffs from stopping in t' (and inducing agent A to disclose in t'). In what follows, we construct the analogous condition when B expects both agent A types to continue between t' and $\tau^* - 2$, the secret holder to disclose in τ^*, and the non-secret holder A_0 to stop in τ^*. If B continues in t' it obtains expected payoffs of $(1-\theta)\left[V(t') - P(t'|\tau^*)\right]$ with probability $\pi_{t'}$ (when agent A is expected to be secret holder) and

$$(1-\theta)\left[\sum_{k=0}^{\tau^*-t'-1} p^k (1-p)\, v(t'+k) + p^{\tau^*-t'} v(\tau^*-1)\right]$$

with probability $1-\pi_{t'}$ (when agent A is expected to be a non-secret holder). Thus, if both agent A types continue in all $t' \le \tau^* - 2$, agent B continues in all $t' \le \tau^* - 1$ if

$$\pi_{t'}\left[V(t') - P(t'|\tau^*)\right] + (1-\pi_{t'})\left[\sum_{k=0}^{\tau^*-t'-1} p^k (1-p)\, v(t'+k) + p^{\tau^*-t'} v(\tau^*-1)\right] \ge \frac{U_B(S|t')}{1-\theta}. \tag{A19}$$

Condition (A18) is more restrictive than (A19) if the LHS of (A19) is at least as large as the LHS of (A18). This is the case if

$$\pi_{t'}\left[P(t'|\tau^a) - P(t'|\tau^*)\right] - (1-\pi_{t'})\left[V(t') - \sum_{k=0}^{\tau^*-t'-1} p^k (1-p)\, v(t'+k) - p^{\tau^*-t'} v(\tau^*-1)\right] \ge 0.$$

Observe that

$$\begin{aligned} & V(t') - \sum_{k=0}^{\tau^*-t'-1} p^k (1-p)\, v(t'+k) - p^{\tau^*-t'} v(\tau^*-1) \\ = \ & V(t') - v(t') - \sum_{k=1}^{\tau^*-t'-1} p^k \left[v(t'+k) - v(t'+k-1)\right] \end{aligned}$$

and

$$V(t') - v(t') = \sum_{k=1}^{\infty} p^k \left[v(t'+k) - v(t'+k-1)\right],$$

so

$$\begin{aligned} & V(t') - v(t') - \sum_{k=1}^{\tau^*-t'-1} p^k \left[v(t'+k) - v(t'+k-1)\right] \\ = \ & p^{\tau^*-t'-1} \sum_{k=1}^{\infty} p^k \left[v(\tau^*+k) - v(\tau^*+k-1)\right] \\ = \ & p^{\tau^*-t'-1}\left[V(\tau^*-1) - v(\tau^*-1)\right]. \end{aligned}$$

Collecting terms, (A18) is more restrictive than (A19) if

$$\pi_{t'}\left[P(t'|\tau^a) - P(t'|\tau^*)\right] \ge (1-\pi_{t'}) p^{\tau^*-t'-1}\left[V(\tau^*-1) - v(\tau^*-1)\right],$$

which is condition (27) in the text. Condition (27) implies the following: If $\pi_{t'} \leq \bar{\pi}_{t'}(\tau^a)$, i.e., if B continues in t' when anticipating that agent A types continue in all t' (Lemma 2), then B continues in t' when it anticipates the secret holder to disclose in τ^* and the non-secret holder A_0 to stop in τ^*. The LHS of (27) is positive and is equal to B's gains when A_1 discloses in $\tau^* < \tau^a$, discounted by the posterior belief $\pi_{t'}$ that $A = A_1$. The RHS of the condition corresponds to the costs that B incurs when the conversation stops in τ^* instead of continuing in all future periods (as it would be under (PE)), discounted by the probability $p^{\tau^*-t'-1}$ of reaching stage $\tau^* - 1$ and the posterior belief $1 - \pi_{t'}$ that $A = A_0$.

For **claim (3)**, analogously to the proof of claim (2), we derive the conditions under which neither agent A types nor agent B have an incentive to deviate from a continuation strategy in any stage $t' < \tau^*$ preceding the signaling game played in τ^* with the hybrid equilibrium (HE) when $\theta = 0$.

Secret holder A_1: Under the hybrid equilibrium (HE), in $t = \tau^*$ agent A_1 is indifferent between disclosing and continuing, implying that

$$U_{A_1}(D|\tau^*) = \beta^* U_{A_1}(C|\tau^e) + (1 - \beta^*)\, \bar{U}_{A_1}(C|\tau^* + 1).$$

with β^* the probability of B choosing to continue and $1 - \beta^*$ the probability of B choosing to stop. Moreover, A_1 is indifferent between disclosing and any mixture of disclosing and continuing, implying that

$$U_{A_1}(D|\tau^*) = \alpha_1^* U_{A_1}(D|\tau^*) + (1 - \alpha_1^*) \left[\beta^* U_{A_1}(C|\tau^e) + (1 - \beta^*)\, \bar{U}_{A_1}(C|\tau^* + 1)\right].$$

If the secret holder continues in t' and plans to disclose in τ^* with probability α_1^* and continue in τ^* with probability $1 - \alpha_1^*$, its expected payoffs are the same as when it discloses in τ^* with a probability of one (as in the separating equilibrium (SE)). By equation (16), these expected payoffs are $V(t') + P(t'|\tau^*)$. Suppose B continues in all $t' \leq \tau^* - 1$, the secret holder continues in all $t' \leq \tau^* - 2$ if, and only if,

$$\frac{V(t') + P(t'|\tau^*) - (1 + \sigma(t'))\, v(t'-1)}{v(t') - v(t'-1)} \geq 1, \tag{A20}$$

which is equivalent to condition (A15) for $\theta = 0$. Because (A15) always holds when (6) is satisfied, (A20) always holds when (6) is satisfied.

Non-secret holder A_0: Under (HE), the non-secret holder A_0 continues with certainty in $t = \tau^*$ and B continues in $t+1$ with a probability between 0 and 1. The non-secret holder A_0's payoffs from continuing in t' are therefore higher than under the separating equilibrium when evaluated for $\theta \to 0$. Because the non-secret holder A_0 continues under the separating equilibrium (since (A17) holds for $\theta \to 0$), it also continues under the hybrid equilibrium.

Agent B: Under (HE), in $t+1 = \tau^*+1$ agent B is indifferent between continue and stop. Hence, its payoffs from continue given the anticipated (or expected) disclosure by A_1 in $\tau^e \in (\tau^*, \tau^a)$ are equal to its expected equilibrium payoffs in $\tau^* + 1$. When $A = A_1$, these payoffs are $V(t') - P(t'|\tau^e)$ with probability $\pi_{t'}$ and expected payoffs of $V(t')$ with probability $1 - \pi_{t'}$ (recall, the non-secret A_0 holder continues with certainty). It's expected payoffs from continuing under the hybrid equilibrium are then $V(t') - \pi_{t'} P(t'|\tau^e)$. Hence, if both agent A types continue in all $t' \leq \tau^* - 2$, agent B continues in all $t' \leq \tau^* - 1$ if

$$V(t') - \pi_{t'} P(t'|\tau^e) \geq U_B(S|t').$$

This condition is less restrictive than condition (A18) under the pooling equilibrium because $V(t') - \pi_{t'} P(t'|\tau^e) \geq V(t') - \pi_{t'} P(t'|\tau^a)$, or, because $\tau^e < \tau^a$,

$$\pi_{t'} \left[P(t'|\tau^a) - P(t'|\tau^e)\right] > 0. \tag{A21}$$

This latter condition is equivalent to condition (28) and always holds true

To establish claims (2) and (3) in the proposition, we recapitulate. Let condition (6) be satisfied and suppose $\tau^* > 1$. When anticipating that B continues in all $t' \leq \tau^* - 1$, both agent A types continue in all $t' \leq \tau^* - 2$ if $\theta > 0$ is small (for (SE)) or $\theta = 0$ (for (HE)). Agent B, when anticipating that both agent A types continue in all $t' \leq \tau^* - 2$, continues in all $t' \leq \tau^* - 1$ if $\pi_{t'} \leq \bar{\pi}_{t'}(\tau^a)$ (i.e., condition (21) holds) and condition (27) holds. We have defined $t = \tau^*$ as the lowest $t \in T_A$ such that $\pi > \bar{\pi}_{\tau^*+1}(\tau^a)$. Because $\tau^* > 1$, it must be that $\pi \leq \bar{\pi}_{t'}(\tau^a)$ for all $t' < \tau^*$. Suppose $\pi > \bar{\pi}_{t'}(\tau^a)$ for $t' < \tau^*$, then by definition of τ^* it must be that $t' = \tau^*$, contradicting $t' < \tau^*$. Recall that B anticipates that both agent A types continue in all $t' \leq \tau^* - 2$. If both agent A types continue, then agent B cannot update its prior beliefs, and $\pi_{t'} = \pi$ for all $t' \leq \tau^* - 1$. Then, $\pi \leq \bar{\pi}_{t'}(\tau^a)$ for all $t' < \tau^*$ implies that $\pi_{t'} \leq \bar{\pi}_{t'}(\tau^a)$ for all $t' < \tau^*$. Hence, a sufficient condition for B to continue in all $t' \leq \tau^* - 1$ is condition (27). Finally, if both agent A types continue and agent B continues in all $t' \leq \tau^* - 1$, then the signaling game in τ^* and $\tau^* + 1$ is reached. Alternatively, let $\tau^* = 1$, then the signaling game is played at the very beginning and the question of whether τ^* is reached does not arise.

[Figure 2 about here.]

In Figure 2 we depict two examples for shapes of the critical threshold $\bar{\pi}_{t+1}(\tau^a)$ for varying $t+1$. In panel (a) the threshold $\bar{\pi}_{t+1}(\tau^a)$ is strictly decreasing in $t+1$. This implies that the smallest $t \in T_A$ such that $\pi > \bar{\pi}_{\tau^*-1}(\tau^a)$ is the unique τ^*. In panel (b) the threshold $\bar{\pi}_{t+1}(\tau^a)$ is hump-shaped. This means there are values of $\pi = \pi'$ such that $\pi' > \bar{\pi}_{t+1}(\tau^a)$ for low $t+1$, $\pi' < \bar{\pi}_{t+1}(\tau^a)$ for intermediate $t+1$, and $\pi' > \bar{\pi}_{t+1}(\tau^a)$ for high $t+1$. For these priors π', the signaling game is played in $t = 1$ and $t = 2$ and $\tau^* = 1$. Q.E.D.

Proof of Proposition 7

Proof. Condition (29) for $\theta \geq 0$ is condition (22) when evaluated in agent B's first period, $t = 2$. If at $t = 2$, the critical value $\bar{\pi}_t(\tilde{\tau})$ in Lemma 2 (for $\tilde{\tau} = \tau^a = \infty$) is strictly less than unity, then for $\pi = 1$ condition (21) is violated and agent B stops in $t = 2$. Because condition (23) is satisfied, the secret holder discloses in $t = \tau^* = 1$ with certainty (Proposition 3 for $\theta > 0$)

or strictly positive probability (Proposition 4 for $\theta = 0$). The conditions in Proposition 6 for conversation to reach τ^* do not apply since $\tau^* = 1$. Q.E.D.

B Pure-Strategy PBE When Condition (23) is Violated

For the analysis in the text we assume that condition (23) in Lemma 3 holds true. This assumption implies that for the secret holder it is more important to continue the conversation than concealing the secret and extracting higher rents in $t+1$. We now provide equilibrium results when this condition (23) is violated. The secret holder will continue the conversation when it anticipates agent B to stop because condition (21) in Lemma 2 is violated. The equilibrium in pure strategies is the following:

PROPOSITION B1. *Let condition (6) be satisfied and condition (23) be violated. If B's prior beliefs are high, $\pi > \bar{\pi}_{t+1}(\tau^a)$, the game of conversation with secrets has a unique pure-strategy PBE. This separating equilibrium is*

$$\{(C,S),(S,C);(\pi^C_{t+1}=1,\pi^D_{t+1}=1)\}. \tag{SE'}$$

Proof. Suppose condition (21) with $\tilde{\tau}=\tau^a$ is violated for some $t+1$, B stops in $t+1$ if agent A continues in t so that $s^C_{t+1}=S$. If (23) is violated a secret holder A_1 who anticipates B to stop in $t+1$ when $s_t=C$ strictly prefers continue to disclose so that $s^1_t=C$, and agent B stops. For $\theta \geq 0$ a non-secret holder A_0 who anticipates $s^C_{t+1}=S$ (weakly) prefers stop to continue in t so that $s^0_t=S$. After $s^0_t=S$ the game ends and no information set for B is reached in $t+1$. For $s_t=s^1_t=C$, B updates its beliefs on the equilibrium path, $\pi^C_{t+1}=1$. The equilibrium action profile for agent A in period t is $(s^{1*}_t,s^{0*}_t)=(C,S)$. Indeed, any arbitrary out-of-equilibrium beliefs ($\pi^D_{t+1}\in[0,1]$) support the equilibrium. By virtue of verifiably disclosing the secret, $\pi^D_{t+1}=1$, and by condition (23) being violated the secret holder A_1 prefers continue (with B stopping in $t+1$) to disclose (with B continuing in $t+1$). No agent A type will deviate from $(s^{1*}_t,s^{0*}_t)=(C,S)$.

To show that (SE') is the unique pure-strategy PBE, we consider the following five remaining strategy profiles: (C,C), (D,C), (D,S), (S,S), and (S,C). Profiles (D,C), (S,S), and (S,C) are not equilibrium profiles by the same arguments as in the analysis that assumes that condition (21) is violated and (23) is satisfied (Proof of Propositon 3). Given (C, C), agent A_0 has a (weak) incentive to deviate; and (D, S) is not an equilibrium because (23) is violated. Hence, if both conditions (21) and (23) are violated, the separating equilibrium (SE') is the unique pure-strategy PBE. Q.E.D.

LEMMA B1. *The pure-strategy PBE (SE') survives the Intuitive Criterion and D1 for all θ.*

Proof. Intuitive Criterion: $\tilde{\mathscr{A}_t} = \{D\}$ and $\mathscr{P}(D) = \{A_1\}$. Because $\pi_{t+1}^D = 1$, $BR(\mathscr{P}(D), D) = \{C\}$. *Step 1:* The (highest) payoff associated with $s_t^1 = D$ and $s_{t+1} = S \in BR(\mathscr{P}(C), C)$ is $U_{A_1}(D|t)$ which is, by condition (23) violated, smaller than the equilibrium payoff $\bar{U}_{A_1}(C|t+1)$. Condition (A7) is violated for type A_1. Hence, $\Theta(D) = \emptyset$. (SE') survives the *Intuitive Criterion* refinement for all θ. *D1:* For (SE'), $\tilde{\mathscr{A}_t} = \{D\}$. Because $\Theta(D) = \emptyset$, (SE') survives *D1.* Q.E.D.

Of course, mixed-strategy equilibria exist, but their properties with respect to termination of the conversation are analogous to the pure-strategy equilibria.

C Model Results Under Implied Waiver

In this appendix we provide the formal proofs for the results on *implied waiver* in Section 5.1. A court-stipulated *waiver* means that if a patent has not been disclosed by the time the standard-setting process comes to an end it is considered to be waived. This has the following effect on function σ: If $\tau \geq \bar{t}$, i.e., if disclosure is *ex post* or after the terminal period $\bar{t}$, then $\sigma(\tau) = 0$. To ease the analysis, we further assume that $v(\cdot)$ is continuous and increasing at a diminishing rate, with $v(0) = 0$ and $v(\infty) = 1$. Moreover, $\sigma(\cdot)$ is continuous with $\sigma(\infty) = 1$.

First, note that post-disclosure conversation is not affected by the *implied waiver*. Thus, condition (10) is satisfied because (6) is satisfied. Next, for conversation before disclosure, note that the patent holder faces a new trade-off when deciding whether to disclose *ex post*. If it has not disclosed its patent by the time the standardization process comes to an end, the patent is invalid (i.e., *waived*). Unlike in the main model, delaying disclosure, say from t to $t+2$, comes at a cost. Given that firm B's communication incentives are not binding (it will always continue), with probability $1-p^2$ firm A will not reach stage $t+2$ and will thus not get to disclose. It will then lose its bargaining leverage and fraction $\sigma(t)$ of B's profits. Conversely, by not delaying but disclosing in t, the patent holder foregoes some license fees because $\sigma(t) < \sigma(t+2)$. In what follows below, we show how the patent holder solves this trade-off.

Aspired Disclosure Our approach to patent holder A_1's disclosure decision is as follows: Because at any t, A_1 cannot commit to disclose at any $t+k$, $k \geq 2$, it 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 $t+2$), $U_{A_1}(C|t+2)$, are at least as high as the expected payoffs from disclosure in t, $U_{A_1}(D|t)$. Because of the lack of commitment, this does not imply that A_1 indeed discloses in $t+2$, but it will then reconsider its decision.

The patent holder's expected payoffs from disclosure in t (when both firms continue after disclosure) are

$$U^W_{A_1}(D|t) \;\; = \;\; (1-\theta)\left[V(t)+\sigma(t)V(t)\right]. \tag{C22}$$

The patent holder's expected payoffs from delayed disclosure in $t+2$ are

$$U^W_{A_1}(C|t+2) \;\; = \;\; (1-\theta)\left[V(t)+p^2\sigma(t+2)V(t+2)\right]. \tag{C23}$$

The payoffs from stop at t are

$$U^W_{A_1}(S|t) \;\; = \;\; v(t)-\theta v(t-1). \tag{C24}$$

We proceed by showing the timing of *aspired* disclosure, that is, the timing of disclosure when firm B's communication constraints are satisfied. This implies that A_1 will continue and delay disclosure for all t as long as

$$U^W_{A_1}(C|t+2) \;\; \geq \;\; U_{A_1}(D|t).$$

In Lemma C1 we show that the patent holder will always delay disclosure. This means, A_1's *aspired* disclosure date is $\tau^a \geq 3$. This is because patent holder A's payoffs from disclosure in $t=1$ are strictly smaller than the payoffs from continuing and disclosing in $t=3$.

LEMMA C1. *The patent holder A_1 delays disclosure of its patent so that $\tau^a \geq 3$.*

Proof. At $t=1$, immediate disclosure by A_1 yields expected payoffs of

$$U^W_{A_1}(D|1) \;\; = \;\; (1-\theta)\,V(1),$$

because $\sigma(1)=0$. Delaying disclosure one round, so that A_1 discloses at $t=3$, yields expected payoffs (evaluated at $t = 1$) of

$$U^W_{A_1}(C|3) \;=\; (1-\theta)\left[V(1) + p^2\sigma(3)V(3)\right].$$

It follows immediately that disclosure at $t = 1$ is dominated by disclosure at $t = 3$ for all $\sigma > 0$ and $p > 0$. Q.E.D.

In a regime with *implied waiver*, the patent holder will not disclose immediately. Unlike in the regime without waiver (Lemma 1), however, A_1 will not wait until the conversation process has come to an end to disclose. If the process allows, meaning if enough new ideas arrive, A_1 will always find it optimal to disclose in a finite τ^a, i.e., *before* the process stops. If the process comes to an end before this τ^a, then the aspired disclosure date cannot be realized, and the patent is invalid. We summarize in Lemma C2.

LEMMA C2. *The aspired disclosure date, $\tau^a > 1$, is finite.*

Proof. For simplicity and without loss of generality, we assume that $t \in (1, \infty) \subset \mathbb{R}_+$. Consider the following properties of the expected payoff functions $U^W_{A_1}(D|t)$ in equation (C22) and $U^W_{A_1}(C|t+2)$ in equation (C23).

P1. $U^W_{A_1}(D|t)$ lies in a bounded space because $\sigma(t)$ and $v(t)$ are bounded and continuous functions, and $V(t) = \sum_k^{\infty} p^k (1-p)\, v(t+k)$ is a bounded sequence.

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

$$\lim_{t\to\infty} U^W_{A_1}(D|t) \;=\; (1-\theta)\,2,$$
$$\lim_{t\to\infty} U^W_{A_1}(C|t+2) \;=\; (1-\theta)\left[1 + p^2\right].$$

Because $p < 1$, in the limit the expected payoffs from delaying disclosure one round are *strictly* smaller than the payoffs from disclosing right away,

$$\lim_{t\to\infty} U^W_{A_1}(D|t) \;>\; \lim_{t\to\infty} U^W_{A_1}(C|t+2). \qquad \text{(C25)}$$

From Lemma C1 we know that in $t = 1$ the patent holder will delay disclosure, because $U^W_{A_1}(D|1) < U^W_{A_1}(C|3)$; condition (C25) implies that in the limit firm the patent will *not* delay disclosure any further. By the intermediate value theorem (and if $U^W_{A_1}(D|t)$ and $U^W_{A_1}(C|t+2)$ intersect at most once), there exists a finite value of $t' > 1$ such that $U^W_{A_1}(C|t+2) > U^W_{A_1}(D|t)$ for all $1 < t < t'$ and $U^W_{A_1}(C|t+2) \leq U^W_{A_1}(D|t)$ for all $t \geq t'$. Setting $\tau^* = t'$ establishes the proof.

If $U^W_{A_1}(D|t)$ and $U^W_{A_1}(C|t+2)$ intersect more than once, there exist multiple finite values of $t' > 1$ such that $U^W_{A_1}(C|t+2) > U^W_{A_1}(D|t)$ for some $t < t'$ and $U^W_{A_1}(C|t+2) \leq U^W_{A_1}(D|t)$ for some $t \geq t'$. Then τ^a is the smallest of these t'. This is because A_1 cannot commit to disclose in $t+k$ for any $k \geq 2$. Once delaying disclosure one round is less profitable than disclosing right away, A_1 will disclose because delaying disclosure more than one round (so that disclosure in $t+4$ or $t+6$) is not an option. Q.E.D.

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

LEMMA C3. *Let both firms' pre-disclosure communication incentives be satisfied. The patent holder A_1 delays patent disclosure but plans to disclose at a finite stage τ^a. This aspired disclosure date τ^a is equal to the smallest $t' > 1$, $t' \in T_A$, such that*

$$U^W_{A_1}(D|t) < U^W_{A_1}(C|t+2) \tag{C26}$$

for all $1 \leq t < t'$, and $U^W_{A_1}(D|t) > U^W_{A_1}(C|t+2)$ for some $t' \leq t < t'+2$.

The patent holder's disclosure is timely, i.e., not subject to the *implied waiver*, with probability p^{τ^a}.

Constrained Disclosure We now consider the disclosure decision of the patent holder accounting for firm B's incentives to continue the process before disclosure. Let π_t denote B's beliefs in $t \in T_B$ about agent A's type and let $\tilde{\tau} \geq t$ denote the period in which B anticipates a patent holder A_1 to disclose the patent. Then B's payoffs from continuing in t under a conversational equilibrium are

$$U_B^W(C|\tilde{\tau}) = (1-\theta)\left[V(t) - \pi_t P^W(t|\tilde{\tau})\right]. \tag{C27}$$

where, by the *implied waiver*,

$$P^W(t|\tilde{\tau}) \quad = \quad p^{\tilde{\tau}-t}\sigma(\tilde{\tau})V(\tilde{\tau}). \tag{C28}$$

If B stops in t so that A_1 discloses in t (*ex post* so that $\sigma(t) = 0$), then B's payoffs are

$$U_B(S|t) = v(t) - \theta v(t-1). \tag{C29}$$

The following lemma describes B's best response when it anticipates a patent holder to disclose the patent in $\tilde{\tau} \in T_A$ and to continue in all other $t \in T_A \setminus \{\tilde{\tau}\}$.

LEMMA C4. *Let condition (6) be satisfied and let B anticipate a patent holder's ex ante disclosure in $\tilde{\tau}$. Firm B continues in $t < \tilde{\tau}$ if, and only if,*

$$\pi_t \leq \bar{\pi}_t^W(\tilde{\tau}) \equiv \frac{(1-\theta)V(t) - [v(t) - \theta v(t-1)]}{(1-\theta)\, P^W(t|\tilde{\tau})} \tag{C30}$$

where $\bar{\pi}_t^W(\tilde{\tau}) > 0$ for all θ and p. Moreover, if $t \to \tilde{\tau}$ and $\tilde{\tau}$ is large enough, then $\bar{\pi}_t^W(\tilde{\tau}) \leq 1$.

Proof. Condition (C30) follows directly from the comparison of (C27) and (C29). First, note that the numerator of $\bar{\pi}_t(\tilde{\tau})$ is non-negative if (6) is satisfied (and strictly positive if (6) is slack). Using the definition of $P^W(t|\tilde{\tau})$ in (C28), $\bar{\pi}_t^W(\tilde{\tau})$ lies within the unit interval if

$$(1-\theta)\left[V(t) - p^{\tilde{\tau}-t}\sigma(\tilde{\tau})V(\tilde{\tau})\right] \quad \leq \quad [v(t) - \theta v(t-1)]\,. \tag{C31}$$

The RHS of (C31) is positive for all $\theta \geq 0$. The LHS of (C31) goes to zero as $t \to \tilde{\tau}$ and

$\tilde{\tau} \to \infty$. Indeed, if $t \to \tilde{\tau}$ then $p^{\tilde{\tau}-t} \to 1$, and if $\tilde{\tau} \to \infty$ then $\sigma(\infty) = 1$. Hence,

$$\lim_{t \to \tilde{\tau}} \left[\lim_{\tilde{\tau} \to \infty} \left[V(t) - p^{\tilde{\tau}-t} \sigma(\tilde{\tau}) V(\tilde{\tau}) \right] \right] = 0 \leq \lim_{t \to \tilde{\tau}} \left[\lim_{\tilde{\tau} \to \infty} \left[v(t) - \theta v(t-1) \right] \right].$$

Q.E.D.

Lemma C5 below describes firm A's best response when it anticipates firm B to continue in all periods up to $t-1$ and to stop in $t+1$.

LEMMA C5. *Suppose period t is reached. Let condition (6) be satisfied and let condition (21) be violated so that firm B stops in $t+1$ if $s_t = C$.*

1. *The non-patent holder A_0 stops in t if $\theta > 0$. For $\theta = 0$, A_0 is indifferent between stopping and continuing in t.*

2. *The patent holder A_1 discloses in t.*

Proof. First note that for t to have been reached without the patent disclosed, all agents must have continued in all $t' < t$.

1. The behavior of the non-patent holder A_0 is as in Proposition 1 and Lemma 3.

2. For the patent holder A_1, the payoffs from stopping in t are

$$U^W_{A_1}(S) = v(t) - \theta v(t-1), \tag{C32}$$

   because it cannot disclose and extract $\sigma > 0$ after the conversation stops in t in the regime with *implied waiver*. By Proposition 2, and condition (6) satisfied, B continues in $t+1$ if A_1 discloses in t. Moreover, both firms then continue in all $t' > t+1$ until a new idea fails to arrive. The patent holder's payoffs from disclosing in t are thus equal to $U^W_{A_1}(D|t)$ in equation (C22). Observe that stopping is dominated by disclosing if $U^W_{A_1}(D|t) \geq U^W_{A_1}(S|t)$ or

$$(1+\sigma(t)) \frac{V(t) - v(t-t)}{v(t) - v(t-1)} \geq \frac{1}{1-\theta}. \tag{C33}$$

Because (6) holds and $\sigma(t) > 0$ unless for $t = 1$ when $\sigma(1) = 0$ (so that (6) and (C33) are equivalent), this condition always holds. We therefore focus on A_1's decision to either disclose in t or continue in t. If the patent holder continues in t, then by condition (C30) in Lemma 2 being violated in $t+1$, firm B will stop in $t+1$ and conversation ends. The patent holder's payoffs from continuing in t when B stops in $t+1$, so that $\sigma = 0$, are

$$\bar{U}^W_{A_1}(C) \quad = \quad (1-\theta)\,v(t). \tag{C34}$$

Therefore, the patent holder discloses in t, because $U^W_{A_1}(D|t) > \bar{U}^W_{A_1}(C|t+1)$. Q.E.D.

For a patent holder it is never optimal to stop or continue in t. Disclosing in t has two implications: The first is to avoid the consequences of the *implied waiver*, the second is to salvage the conversation process because (given the post-disclosure communication condition (6) holds) B will continue in $t+1$ and all future periods. Therefore, unlike in the framework of the main model where the patent holder's decision to disclose depends on condition (23), here the patent holder always discloses when it anticipates firm B to stop otherwise.

Combining our findings from Lemmata C3, C4, and C5 for the firms' best responses gives rise to two distinct scenarios. In the first, a date $t+1$ in which condition (C30) is violated is never reached, because the patent holder discloses in $\tau^a < t+1$. In the second case, the date $t+1$ in which condition (C30) is violated is reached before τ^a. In this latter scenario, two sub-cases might arise, and both are equivalent to the cases considered for the proof of Proposition 3. In the first, condition (C30) is satisfied in $t+1$ so that B continues in $t+1$ when A continues in t. The second sub-case is the one in which (C30) is violated for $t+1$ so that B stops if A continues in t. Proposition C1 illustrates the unique pure-strategy equilibrium in each of these two sub-cases.

PROPOSITION C1. *Let condition (6) be satisfied.*

1. *If B's prior beliefs are low, $\pi \leq \bar{\pi}^W_{t+1}(\tau^a)$, the patent disclosure game has a unique pure-*

strategy PBE. This pooling equilibrium is

$$\{(C,C),(C,C);(\pi^{C}_{t+1}=\pi,\pi^{D}_{t+1}=1)\}. \tag{PE''}$$

2. *If B's prior beliefs are high, $\pi > \bar{\pi}^{W}_{t+1}(\tau^{a})$, the patent disclosure game has a unique pure-strategy PBE. This separating equilibrium is*

$$\{(D,S),(S,C);(\pi^{C}_{t+1}>\bar{\pi}_{t+1}(\tau^{a}),\pi^{D}_{t+1}=1)\}. \tag{SE''}$$

Proof. The proof follows the same steps as in Proposition 3. Q.E.D.

At last, to establish that the conversation reaches the period t in which the signaling game in Proposition C1 is played when the patent holder has not disclosed before t, the analysis is analogous to the one in Section 4.3.

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Figure 1: Conversation Game with Secrets

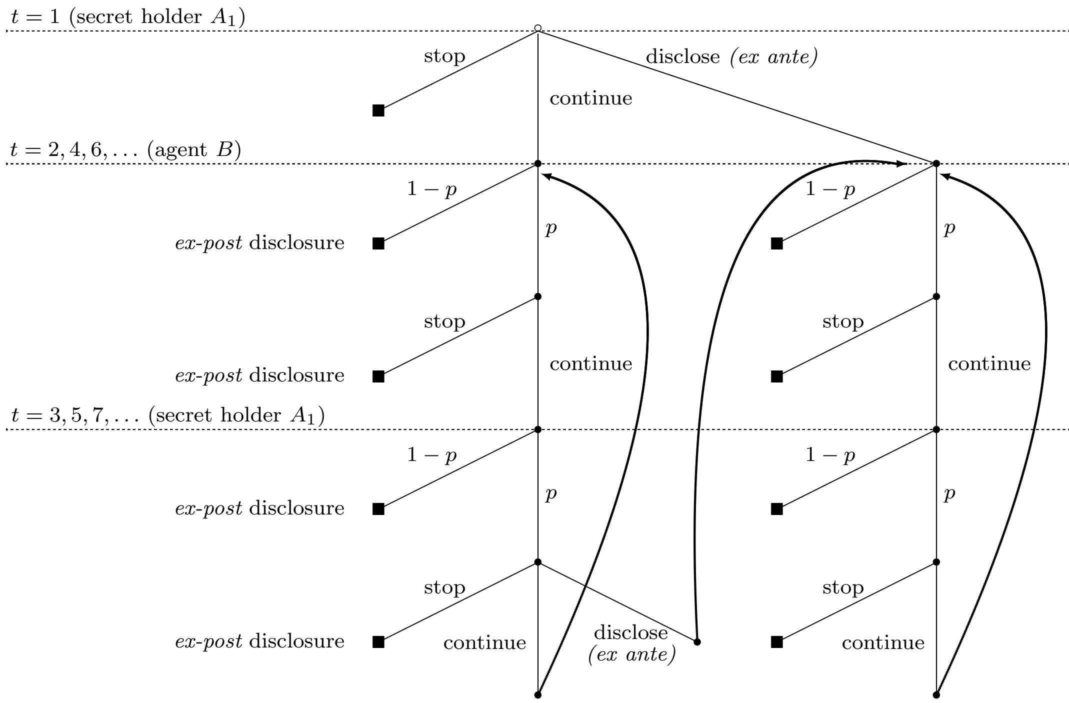
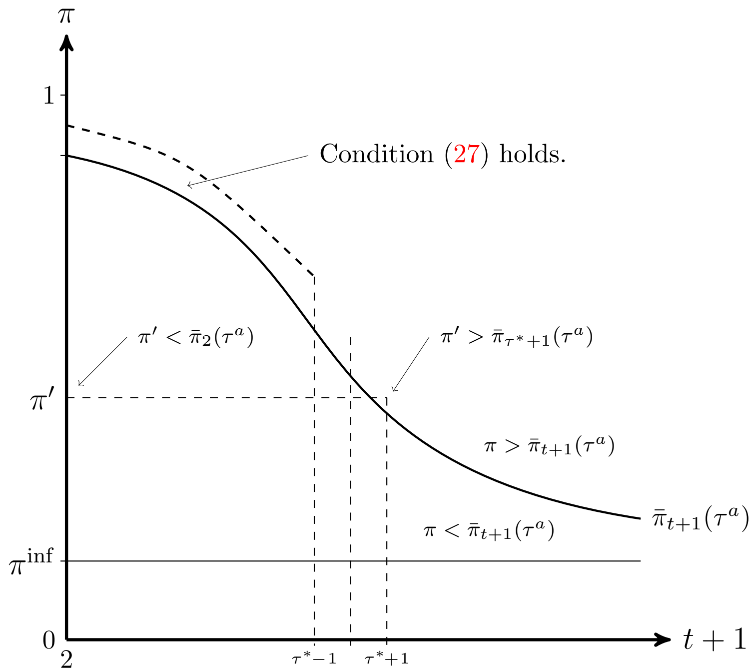
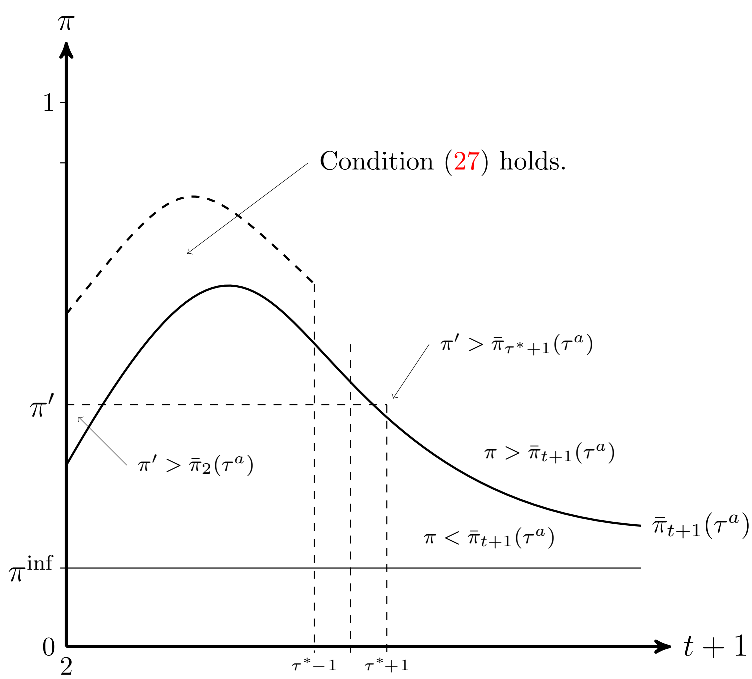


Figure 2: Shapes of $\bar{\pi}_{t+1}(\tau^a)$



(a) Decreasing $\bar{\pi}_{t+1}(\tau^a)$



(b) Hump-Shaped $\bar{\pi}_{t+1}(\tau^a)$

Table 1: Overview of Equilibrium Results

	No competition: $\theta = 0$	Competition: $\theta > 0$
Low prior beliefs: $\pi \leq \pi^{\text{inf}}$	**Pooling Equilibrium** (PE) *1)* Conversation is sustainable for both agent A types. *2)* *Ex-post* disclosure.	
High prior beliefs: $\pi > \pi^{\text{inf}}$	**Hybrid Equilibrium** (HE) *1)* Conversation is sustainable in $t < \tau^*$ and sustainable with positive probability in $t \geq \tau^*$. *2)* *Ex-ante* disclosure in τ^* or later.	**Separating Equilibrium** (SE) *If condition* (27) *holds and* θ *small:* *1)* Conversation is sustainable in $t < \tau^*$ but sustainable in $t \geq \tau^*$ only for the secret holder. *2)* *Ex-ante* disclosure in τ^*.
$\pi > \bar{\pi}_2(\tau^a)$	**Hybrid Equilibrium** (HE) *1)* Conversation is sustainable with positive probability in $t \geq \tau^* = 1$. *2)* *Ex-ante* disclosure in $\tau^* = 1$ or later.	**Separating Equilibrium** (SE) *Immediate disclosure* *1)* Conversation is sustainable in $t \geq \tau^* = 1$ only for the secret holder. *2)* *Ex-ante* disclosure in $\tau^* = 1$.
$\bar{\pi}_2(\tau^a) < 1$ and $\pi = 1$	*Immediate disclosure* *1)* Conversation is sustainable in all $t \geq \tau^* = 1$ *2)* *Ex-ante* disclosure in $\tau^* = 1$.	

Table 2: Numerical Example for $v(t) = 1 - (9/10)^t$, $\sigma(t) = 1 - (9/10)^t$, and $p = 1/2$

	$\theta = 0$ $\pi^{\text{inf}} = 0.31$	$\theta = 1/10$ $\pi^{\text{inf}} = 0.28$	$\theta = 4/10$ $\pi^{\text{inf}} = 0.08$
$\pi = 1/4$	**Pooling Equilibrium** *Ex-post* disclosure	**Pooling Equilibrium** *Ex-post* disclosure	**Separating Equilibrium** Disclosure in $t = 1 < \tau^* = 3$ *(Condition (27) violated)*
$\pi = 3/4$	**Hybrid Equilibrium** Disclosure in $\tau^* = 5$ or later	**Separating Equilibrium** Disclosure in $\tau^* = 3$	**Separating Equilibrium** Disclosure in $\tau^* = 1$
$\pi = 1$	Disclosure in $\tau^* = 3$	Disclosure in $\tau^* = 3$	Disclosure in $\tau^* = 1$