

# Optimal Disclosure Windows\*

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## Abstract

I study a dynamic disclosure game in which an agent controls the time window over which information flows to the decision maker, but does not control the content of that information. In equilibrium, the agent has incentives to delay the start of disclosure to continue to learn privately for some time. This delay exacerbates the information asymmetry between the agent and the decision maker as the agent is learning while the decision maker is not. The length of the disclosure window is determined by the degree of information asymmetry at the beginning of the window, with longer windows associated with greater information asymmetry. As a result, the delay in the start of disclosure requires a longer disclosure window.

**Keywords:** information disclosure, strategic timing, dynamic signaling.

**JEL Codes:** C73, D82, D83

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# 1 Introduction

I study a novel dynamic model of verifiable information disclosure. I consider a disclosure environment in which an agent, who observes a flow of information over time, controls the window of time over which this information is released to a decision maker, but does not control the content of the information being released. The agent chooses when to open this disclosure window and how long to keep it open, taking into account that while disclosure is progress, he cannot prevent unfavorable information from coming to light.

This disclosure environment is common in many corporate and financial settings. For example, consider a pharmaceutical company (the agent) seeking drug approvals from the Food and Drug Administration (FDA, the decision maker). The pharmaceutical company first files for patents to establish proprietary, and (privately) gathers information about the drug through discovery and preclinical research. It then registers the drug with the FDA to start clinical trials. At this point, the company must report all results from clinical trials. The company then chooses a time to conclude clinical trials, after which it submits a drug application to the FDA, who then decides the extent (treatment conditions, age groups, etc) to which they approve the drug.<sup>1</sup> Similarly, consider a private company (the agent) trying to raise capital through an Initial Public Offering (IPO). The company is initially privately owned and learns about its potential market value through operations. It announces an IPO when it decides to go public and performs due diligence, where it undergoes investigations into its financials and performances. The company then chooses an initial offering date, at which time the market (the decision maker) evaluates and prices the company.

This disclosure environment prevents the agent from cherry-picking which information to disclose. Instead, the agent (partially) controls the information release by choosing when to open and close the disclosure window based on what he knows and what has been revealed. As the examples above show, sometimes information transparency during a disclosure window is a legal or institutional requirement, and the timing of disclosure is a crucial strategic component in determining the final outcome. The voluntary disclosure literature has largely focused on “*what* to disclose,” while the study of “*when* to disclose” has received relatively little attention.

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<sup>1</sup>Details about the FDA drug approval process can be found at <https://www.fda.gov/patients/learn-about-drug-and-device-approvals/drug-development-process>.

My paper contributes to this literature by studying *when* and *how long* to disclose. I explore the strategic timing of both the beginning and the end of disclosing an information process, whilst capturing the idea that the information arriving during this window of time must be disclosed in full. I characterize the agent’s optimal time to start disclosure and the optimal duration to keep it open, and derive a key insight that delays in the start of disclosure lead to longer disclosure windows.

Specifically, in my model, an agent and a decision maker engage in a dynamic disclosure game that takes place in continuous time with an infinite horizon. The underlying state of the world is either good or bad, initially unknown to the agent and the decision maker. Over time, the agent privately receives a flow of information about the state. The information takes the form of signals that arrive at random times and deliver conclusive news that the state is bad. The agent chooses a time to start disclosing this information process to the decision maker. While the information process unfolds, he chooses a time to stop disclosing. To capture the idea that the beginning and end of a disclosure process are often restricted by exogenous factors such as financing, I assume the agent can start disclosing at any time only after he gets an opportunity to do so, and disclosure might exogenously terminate at any time after it starts. The decision maker observes the times at which disclosure begins and ends and the signal arrivals (or lack thereof) in between, but not the underlying reasons for why disclosure doesn’t begin or why it ends. Given this information, the decision maker takes an action at the end of disclosure. While the decision maker prefers an action that matches the state, the agent prefers a higher action regardless of the state.

This setup poses some analytical challenges. First, this game is effectively a dynamic signaling game with an agent whose (private) information changes over time. Second, the agent choosing both when to start and when to stop disclosing results in two stopping problems that are intertwined. Both issues lead to an obscured inference problem for the decision maker. The standard exponential bandit framework with conclusive bad news helps keep the problem tractable: at each point in time, the agent can either be of only two types: *informed* if he has observed a conclusive bad signal, or *uninformed* if he has not. Although the agent’s belief still changes over time if he is uninformed, the agent’s type can only change from being uninformed to informed. Together with the fact that learning is common knowledge, the decision maker knows the agent’s belief evolution at each point in time.<sup>2</sup>

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<sup>2</sup>In other words, “time 0” is common knowledge. The decision maker does not know what the agent

The equilibrium strategies are as follows. The decision maker takes an action that is equal to her posterior belief about the state at the time disclosure stops. If the agent is patient, then he (both types) delays the start of disclosure for some time in order to privately learn about the state. After having done so, he starts disclosing as soon as he gets the opportunity. If the agent is impatient, he starts disclosing as soon as he gets an opportunity right from the start of the game. Once disclosure has started, the uninformed agent has stronger incentives to keep disclosure open and let information flow to the decision maker. In particular, along the history in which no signal arrives and disclosure does not terminate exogenously, the uninformed agent keeps the disclosure window open until such a time that the decision maker is convinced that the agent is uninformed. While the uninformed agent strictly prefers to keep the disclosure window open until this time, the informed agent is indifferent and randomizes over waiting times within this disclosure window.

The equilibrium captures a novel interaction between the duration of the disclosure window and the time at which it starts: a later start of disclosure leads to a longer disclosure window. The duration of the disclosure window is determined by the degree of information asymmetry between the agent and the decision maker at the beginning of the window. At the beginning of the game, the agent and the decision maker have the same information about the state. Prior to the start of disclosure, the agent learns about the state privately: he either becomes more optimistic that the state is good if he remains uninformed, or receives a signal and becomes informed. Because the two types of agent adopt the same strategy in choosing the start of disclosure, the decision maker cannot infer anything about the state from the agent's behavior and thus is not learning about the state while the agent continues to do so. A longer delay till the start of disclosure exacerbates this information asymmetry between the agent and the decision maker. The now-more-optimistic uninformed agent needs to keep the disclosure window open longer to reduce the difference between his belief that the state is good and that of the decision maker.

At the beginning of the game where the agent chooses when to start disclosure, the agent faces a tradeoff between private learning and discounting. If a signal arrives, the agent would rather observe that signal in private and learn the state without having to share this information with the decision maker. However, delay is costly because of discounting and because a delay in the start of disclosure leads to an even longer delay 

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has learned but does not know how much the agent has learned.

in the continuation game. Thus, the expected time until the payoff realizes is longer. The agent finds it optimal to delay to learn only if he is sufficient patient.

In the continuation stopping game while the disclosure window is open, the agent faces a tradeoff between inducing a more favorable action and higher risks. In the conclusive bad news environment, “no news is good news”: the decision maker (and the agent) become more optimistic that the state is good in the absence of signals. However, a longer disclosure time exposes the agent to higher risks because a signal is more likely to arrive during a longer time interval. This tradeoff leads to delayed stopping by the more optimistic (uninformed) agent as he regards the risk lower than the informed agent does. In equilibrium, the uninformed agent keeps the disclosure window open in the hope that both the absence of signals for a certain length of time, and the fact that he is willing to let information flow for that long, convince the decision maker that he is the uninformed agent; hence the decision maker should be as optimistic as he is.

## Related Literature

My paper contributes to the literature on voluntary disclosure of verifiable information pioneered by [Grossman and Hart \(1980\)](#), [Grossman \(1981\)](#), and [Milgrom \(1981\)](#). These earlier works establish an unraveling result: under certain conditions, all types of agents (or senders) disclose their information and the decision maker (receiver) learns the agent’s type. Subsequent work in this literature has shown that the unraveling result fails if disclosure is costly (see [Jovanovic, 1982](#) and [Verrecchia, 1983](#)), or if the decision maker is uncertain about the agent’s information endowment, that is, whether the agent has information or not (see [Dye, 1985](#) and [Jung and Kwon, 1988](#)). I adopt the approach proposed in [Dye \(1985\)](#) and [Jung and Kwon \(1988\)](#).

As mentioned, most of the existing literature has focused on studying “*what* to disclose” while very few consider “*when* to disclose.”<sup>3</sup> In my paper, the disclosure decision is multi-dimensional, in the sense that not only does the content of the disclosure matter, the timing of disclosure also plays a key role in determining the equilibrium outcome. Some examples that explore the timing of disclosure include [Acharya, De-Marzo, and Kremer \(2011\)](#) and [Guttman, Kremer, and Skrzypacz \(2014\)](#), both of which are dynamic versions of [Dye \(1985\)](#).

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<sup>3</sup>This is pointed out in [Guttman, Kremer, and Skrzypacz \(2014\)](#) where they mention a survey by [Hirst, Koonce, and Venkataraman \(2008\)](#).

Specifically, [Acharya et al. \(2011\)](#) consider a model in which the agent gets one piece of private information and his timing decision to disclose this information is constrained by the arrival of some public information. [Guttman et al. \(2014\)](#) study a two-signal, two-period model where the agent chooses which period to disclose and what signal to disclose. The content of disclosure is completely flexible in [Guttman et al. \(2014\)](#). If the agent waits until the second period to disclose, there is a chance that he might get an additional signal in the second period, and can then choose which signal to disclose. In my model, the agent cannot pick and choose the information he discloses. In fact, the agent’s inability to control the information content is one of the key considerations behind the agent’s timing decisions.

My model features a disclosure environment different from the papers mentioned above. When the agent starts disclosure, he does not disclose a piece of evidence that can be immediately verified. Instead, “disclosure” starts a learning process for the decision maker. In this regard, the most closely related paper is [Gratton, Holden, and Kolotilin \(2018\)](#). Over a finite time horizon, a perfectly informed agent receives a signal process at some random time, and then chooses a time after getting this information to start disclosing this process to the decision maker. Their model highlights a “credibility vs. scrutiny” tradeoff, where the agent signals that his type is good by starting disclosure early, but is exposed to greater scrutiny. The continuation game in my model, although studies the agent’s decision to stop disclosure not start, features a similar tradeoff. There are a few key differences between their model and mine. I consider a model where the agent has the same information as the decision maker at the beginning of the game, but gradually learns about the state over time. More importantly, the agent controls not only when to start disclosure, but also when to stop. I focus on understanding the interactions between these two timing decisions, and the fact that the agent’s information evolves over time is an important determinant of this interaction.

On a more technical level, my model results in a dynamic signaling game with changing types. I consider exponential learning conclusive news (as studied in [Keller, Rady, and Cripps, 2005](#)), which keeps the complications from changing types at bay. [Thomas \(2019\)](#) studies an experimentation problem with reputation concerns where the effect of changing type is more prominent.

## Structure of the paper

I introduce the model in [Section 2](#). In [Section 3](#), I characterize a class of equilibria of the game, and discuss the equilibrium properties and dynamics. Next, in [Section 4](#), I study the duration of the disclosure window, and show that delays in the start of disclosure leads to longer disclosure windows. Lastly, in [Section 5](#), I present a benchmark model where the agent knows the state from the start. I then study an extension that characterizes the decision maker's optimal duration of a disclosure window, and show that the decision maker's incentive to keep the disclosure window open is in contrast to the agent's. All proofs are relegated to the [Appendix](#).

## 2 Model

Time is continuous and the horizon is infinite. There are two players, an agent (he) and a decision maker (she). There is an unknown state of the world  $\theta \in \{0, 1\}$ , where  $\theta = 1$  indicates the state is good and  $\theta = 0$  indicates the state is bad. The players share a common prior about  $\theta = 1$ , denoted by  $\mu \in (0, 1)$ .

### Information

Over time, the agent receives private signals that have Poisson arrival rate  $\lambda^\theta$ , where  $\lambda^1 = 0$  and  $\lambda^0 = \lambda > 0$ . In other words, signals are conclusive that the state is  $\theta = 0$ . This means the agent's posterior belief that  $\theta = 1$  increases in the absence of signals. The agent can receive multiple signals over time, but because signals are conclusive, the agent's belief about the state does not change upon receiving additional signals.

**Agent's (private) belief/types.** Throughout the game, the agent updates his belief about the state through the realization of the signal process. In particular, let  $t_s$  denote the time of the first signal arrival. Define the agent's posterior belief about  $\theta = 1$  conditional on no signals by  $t$  as  $\rho(t) := \Pr(\theta = 1 | t_s \geq t)$ . By Bayes' rule,

$$\rho(t) = \frac{\mu}{\mu + e^{-\lambda t}(1 - \mu)}. \quad (1)$$

This belief  $\rho(t)$  is strictly increasing in  $t$ . If a signal arrives at  $s$ , the agent's belief drops down to 0 for all  $t \geq s$ . The agent's belief remains his private information — even

though the evolution of the signal process will be publicly observable once disclosure starts, the realization beforehand remains private.

At any  $t$ , the agent either has observed a signal and has belief 0 or he has not observed a signal and has belief  $\rho(t)$ . I say that the agent is *informed* at  $t$  if he has observed a signal at or before  $t$ , or *uninformed* at  $t$  if he has not.

## Actions and payoffs

Over time, the agent privately receives an opportunity to start disclosing that has Poisson arrival rate  $\alpha > 0$ . This process is independent of the state and the information process. The agent can start disclosing at any time after the arrival of the opportunity.<sup>4</sup> Suppose the opportunity arrives at time  $t_0$ . If the agent starts disclosing at time  $t_{\text{start}} \geq t_0$ , he commits to disclosing all signal arrivals (or lack thereof) for  $t > t_{\text{start}}$ . The agent cannot disclose the realization of the signal process for  $t \leq t_{\text{start}}$ . The decision maker observes the time at which the agent starts disclosing, namely  $t_{\text{start}}$ , but not the time at which the opportunity arrives, nor can the agent disclose this information.

Once disclosure starts at  $t_{\text{start}}$ , the agent chooses a time  $t_{\text{stop}} \geq t_{\text{start}}$  to stop disclosing. Also starting at time  $t_{\text{start}}$ , an exogenous termination arrives at jumping times of a Poisson process with intensity  $\beta > 0$ . This process is independent of the state. As soon as termination arrives, the game ends. Suppose a termination arrives at time  $t_{\text{term}}$ . The decision maker observes the time at which disclosure ends,  $\min\{t_{\text{stop}}, t_{\text{term}}\}$ , but does not observe whether the end of disclosure is the agent's choice or exogenous.

The decision maker takes an action  $a \in \mathbb{R}$  at and only at the time disclosure stops. The decision maker's realized payoff is  $1 - (a - \theta)^2$  and the agent's realized payoff is  $\kappa + a$ , where  $\kappa > 0$  is constant.<sup>5</sup> Both players collect payoffs at the time disclosure stops, and discount future payoffs at a common discount rate  $r > 0$ .

**Discussion of Assumptions.** The two Poisson arrival processes, opportunity to start disclosing and exogenous termination, capture that the timing of the disclosure window is sometimes restricted by exogenous factors unrelated to the underlying nature

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<sup>4</sup>I assume there is only one such opportunity. Multiple opportunity arrivals do not matter as long as the agent can start disclosing when the first one arrives.

<sup>5</sup>The constant term  $\kappa > 0$  in the agent's payoff indicates delaying is costly: if there exists a time  $\bar{t}$  such that the decision maker takes a fixed action for any  $t \geq \bar{t}$ , the agent strictly prefers stopping disclosing at the earliest time  $\bar{t}$ . The decision maker's payoff constant is strategically irrelevant and is normalized to 1.



of the state. Take the drug approval process for example. The drug company needs to get the relevant paperwork ready, sort out administrative issues, and get financing in order before they can file for clinical trials. Similarly for the end of disclosure, clinical trials might be terminated unexpectedly because of fundings falling through, or a change in the company's leadership where the new board has no interest in developing the drug and wants to wrap up testings as soon as possible (see [Sica, 2002](#) or [Williams, Tse, DiPiazza, and Zarin, 2015](#)).

From a modeling perspective, these two processes provide the noise that prevents the decision maker from getting all of the agent's information upon an observable action.<sup>6</sup> The decision maker observes the times at which disclosure starts and stops, but not the underlying reasons. To be specific, if disclosure has not started, the decision maker does not know whether it is because the agent chooses not to start, or because the agent does not have an opportunity to do so. Similarly, if disclosure stops, the decision maker does not know whether it is because the agent chooses to stop, or because disclosure was exogenously terminated.

## Strategies and solution concept

The strategy of the agent describes when to start and when to stop disclosing. As standard, strategies can be described in terms of probability distribution functions. I focus on strategies that satisfy a Markov restriction, and introduce the formal definition in the context of Markov strategies.

For a mixed starting strategy, let  $\Phi(t|t_0, t_s)$  denote the probability that the agent starts disclosing before or at time  $t$  given that the opportunity arrives at  $t_0 < t$  and the first signal arrives at  $t_s < t$ . Let  $\Phi(t|t_0, \emptyset)$  denote the probability that the agent starts disclosure by time  $t$  given that the opportunity arrives at  $t_0 < t$  and no signal has arrived by time  $t$ . That is, for each  $t_0$  and each  $t_s$ ,  $\Phi(t|t_0, t_s)$  measures, for each  $t$ , the probability to start disclosing by time  $t$ ; for each  $t_0$ ,  $\Phi(t|t_0, \emptyset)$  measures for each  $t$ , the probability to start disclosing by time  $t$ . Note that defining mixed strategy in this way imposes the implicit Markov restriction that the stopping decision depends only on the time of the first signal arrival, even if the agent may have observed more than

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<sup>6</sup>Similar assumptions can be found in, for example, [Ekmekci, Gorno, Maestri, Sun, and Wei \(2022\)](#). They study a game between a principal and an agent, and assume the principal gets stochastic opportunities to terminate her relationship with the agent.

one signal. I impose an additional Markov restriction that specifies

$$\Phi(t|t_0, t'_s) = \Phi(t|t_0, t''_s) \text{ for all } t'_s, t''_s < t_0.$$

That is, if the agent is informed by the time he gets the opportunity to disclose, his stopping decision does not depend on the time at which he becomes informed.

I impose a similar set of Markov restrictions on the stopping strategy. At the time disclosure starts, denoted by  $t_{\text{start}}$ , recall that the agent's private history contains the signal arrivals prior to the start of disclosure, and the time of his opportunity arrival. I impose a Markov restriction that specifies that, instead of the entire private history, the agent's stopping strategy only depends on whether he is informed or uninformed prior to the start of disclosure. Because the game ends when an exogenous termination occurs, a stopping strategy only needs to specify the agent's actions in the absence of termination.

I reason in terms of the waiting time since  $t_{\text{start}}$ . That is, a waiting time  $w$  translates to the calendar time  $t_{\text{start}} + w$ . Denote the time at which the agent stops by  $w$ . Within  $[0, w]$ , signal arrivals are public. I impose a Markov restriction that the agent's stopping strategy depends only on the arrival time of the first public signal. Formally, let  $w_s$  denote arrival of time of the first public signal. Let  $G_I(w|t_{\text{start}}, w_s)$  denote the probability that an informed agent stops disclosure by time  $w$  given disclosure started at  $t_{\text{start}}$  and the first public signal arrives at  $w_s < w$ . Let  $G_I(w|t_{\text{start}}, \emptyset)$  denote the probability that an informed agent stops disclosure by time  $w$  given disclosure started at  $t_{\text{start}}$  and no public signal has arrived by  $w$ . The uninformed agent's probabilities  $G_U(w|t_{\text{start}}, w_s)$  and  $G_U(w|t_{\text{start}}, \emptyset)$  are defined in the same way. I impose an additional Markov restriction that specifies that if a public signal arrives at  $\hat{w}$ ,

$$G_I(w|t_{\text{start}}, \hat{w}) = G_U(w|t_{\text{start}}, \hat{w}).$$

For the decision maker, she takes an action when and only when disclosure ends. Denote this time by  $t_{\text{end}}$ . Note that disclosure ends at the minimum of the time the agent stops or termination arrives. Denote the set of public history at time  $t_{\text{end}}$  by  $\mathcal{H}_{t_{\text{end}}}^{\text{pub}}$  and an element of it  $h_{t_{\text{end}}}^{\text{pub}}$ . Then  $h_{t_{\text{end}}}^{\text{pub}}$  consists of the time at which disclosure starts  $t_{\text{start}}$ , the time at which disclosure stops  $t_{\text{end}}$ , and the evolution of the signal process in  $[t_{\text{start}}, t_{\text{end}}]$ . The decision maker's strategy maps a public history to a real number.

I focus on the set of perfect Bayesian equilibria in which the agent adopts Markov strategies described above (referred to as equilibrium hereinafter). In addition, I use an equilibrium refinement that is in the spirit of the divinity refinement introduced by Banks and Sobel (1987).<sup>7</sup> Divinity specifies that the decision maker should assign zero weight to deviation of the type of agent that has less incentive to deviate. I discuss how divinity plays a role in more detail when I characterize the equilibrium.

### 3 Equilibrium Analysis

In this section, I characterize a class of equilibria of this game. I begin by characterizing the decision maker's equilibrium strategy, and devote the rest of the section to characterizing the agent's.

#### 3.1 Decision Maker's Equilibrium Strategy

The decision maker takes an action at and only at the time disclosure ends,  $t_{\text{end}}$ .<sup>8</sup> A public history at  $t_{\text{end}}$ , denoted by  $h_{t_{\text{end}}}^{\text{pub}}$ , contains the time at which disclosure starts, the time at which disclosure ends, and signal arrivals (or lack thereof) in between. Given any public history  $h_{t_{\text{end}}}^{\text{pub}}$ , the decision maker's maximization problem is

$$\max_{a \in \mathbb{R}} \mathbb{E}_{\sigma} \left[ e^{-rt_{\text{end}}} (\kappa - (a - \theta)^2) \mid h_{t_{\text{end}}}^{\text{pub}} \right],$$

where  $\sigma$  denotes the agent's strategies. This implies that in equilibrium, the decision maker takes an action that is equal to her expectation of the state given the public history. Because the state is either 0 or 1, the expectation is equal to the posterior belief that  $\theta = 1$ . The following lemma summarizes this result.

**Lemma 1.** *In any equilibrium, at the time disclosure ends  $t_{\text{end}}$ , given any public history  $h_{t_{\text{end}}}^{\text{pub}}$ , the decision maker's action is*

$$a = \mathbb{E}_{\sigma}[\theta \mid h_{t_{\text{end}}}^{\text{pub}}] = \Pr(\theta = 1 \mid h_{t_{\text{end}}}^{\text{pub}}).$$

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<sup>7</sup>With a slight abuse of terminology, I refer to this refinement as divinity. It is worth noting that the divinity refinement introduced by Banks and Sobel (1987) cannot be applied directly to a continuous time infinite horizon setting.

<sup>8</sup>Recall that the decision maker does not/cannot take an action if disclosure never ends.

## 3.2 Agent's Equilibrium Strategy

The rest of [Section 3](#) is dedicated to characterizing the agent's equilibrium strategies. The game has two stages: the initial *starting game* where the agent chooses a time to start disclosing, and the continuation *stopping game* where disclosure has started and the agent chooses a time to stop disclosing. Both games are of some substance. To keep the analysis in perspective, I first provide a characterization of the equilibrium and discuss the intuition in [Section 3.2](#). I then analyze the equilibrium in detail and discuss some of the interesting dynamics and properties in [Section 3.3](#) and [Section 3.4](#).

### Equilibrium characterization

[Theorem 1](#) below characterizes a class of equilibria of this game. This class of equilibria features the two types of agent following the same starting strategy and different stopping strategies. Specifically, at the beginning of the game, conditional on having the opportunity, both types of agent delay starting until some time  $\tau^* \geq 0$ .<sup>9</sup> At and after  $\tau^*$ , both types of agent start disclosure as soon as an opportunity arrives. Once disclosure starts, the uninformed agent waits for a certain amount of time  $w^*$  to stop disclosure, while the informed agent randomizes over waiting times in  $[0, w^*]$ .

With a slight abuse of notation, conditional on disclosure starting, let  $G_I(w)$  and  $G_U(w)$  denote respectively the informed and uninformed agent's probability of stopping by  $w$  given no signal in  $[0, w]$  (and no exogenous termination by  $w$ ). That is,  $G_I(w) = G_I(w|N(w) = 0)$  and  $G_U(w) = G_U(w|N(w) = 0)$ . The equilibrium can be stated as follows.

**Theorem 1.A.** *The following strategy is an equilibrium of the starting game. There exists  $\tau^* \geq 0$  such that neither type of agent starts disclosing for  $t < \tau^*$ , and both types of agent start disclosing as soon as an opportunity arrives for  $t \geq \tau^*$ . That is, for all  $t_s$ ,*

$$\Phi(t|t_0, t_s) = \begin{cases} 0 & t < \tau^* \\ 1 & t \geq \max\{\tau^*, t_0\} \end{cases}.$$

*The decision maker's belief that  $\theta = 1$  if disclosure starts is  $\eta(t) = 0$  for  $t < \tau^*$  (where starting disclosure is off-path), and is  $\eta(t) = \mu$  for  $t \geq \tau^*$  (where starting disclosure is on-path).*

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<sup>9</sup>Depending on the parameters,  $\tau^*$  can be 0 which means the agent does not delay.

**Theorem 1.B.** *Suppose disclosure starts at  $t \geq \tau^*$ . In equilibrium, there exists a waiting time  $w^* \geq 0$  (where  $w^*$  depends on  $t$ ) such that*

- (i) *if a signal arrives at  $w \in [0, w^*]$ , the agent stops disclosing immediately at  $w$ ;*
- (ii) *if no signal arrives in  $[0, w^*]$ , the uninformed agent stops disclosing at  $w^*$  with probability 1:*

$$G_U(w) = \begin{cases} 0 & w \in [0, w^*) \\ 1 & w \geq w^* \end{cases}. \quad (2)$$

*The informed agent randomizes over waiting times in  $[0, w^*]$ . His stopping probability  $G_I(w)$  is the unique solution to the following boundary value problem: for all  $w \in [0, w^*]$ ,*

$$G_I''(w) = \mathcal{G}(G_I(w), G_I'(w), w) \quad (3)$$

*with boundary conditions*

$$G_I(0) = 0, G_I(w^*) = 1, \text{ and } G_I'(w^*) = 0. \quad (4)$$

*The definition of  $\mathcal{G}$  is in the [Appendix](#).*

**Theorem 1.A** characterizes the agent's strategies in the starting game. The agent either delays starting disclosure ( $\tau^* > 0$ ), or immediately starts disclosure ( $\tau^* = 0$ ) as soon as an opportunity arrives. The parametric restriction that defines these two cases comes down to how discounting compares to the rate of signal arrival. Loosely speaking, because the decision maker only takes the action when disclosure ends, a delay in the start of disclosure results in a cost due to discounting. The benefit, on the other hand, is the agent's ability to privately learn about the state: if a (conclusive bad) signal arrives while the agent is waiting, he learns that the state is bad but does not have to share that information with the decision maker. Therefore, delaying the start of disclosure is beneficial if discounting is small comparing to the rate of signal arrival.

**Theorem 1.B** characterizes the agent's strategies in the stopping game. While disclosure is open, the longer the decision maker has not seen a signal, the more optimistic she becomes. However, the risk of a signal arriving also increases. This tradeoff leads to delayed stopping by the more optimistic (uninformed) agent.

The equilibrium dynamics are best illustrated in terms of belief evolution the decision maker. **Figure 1** plots an example of the decision maker's (on-path) belief conditional on no signal arrivals in an equilibrium with initial delay till time  $\tau^* > 0$ .

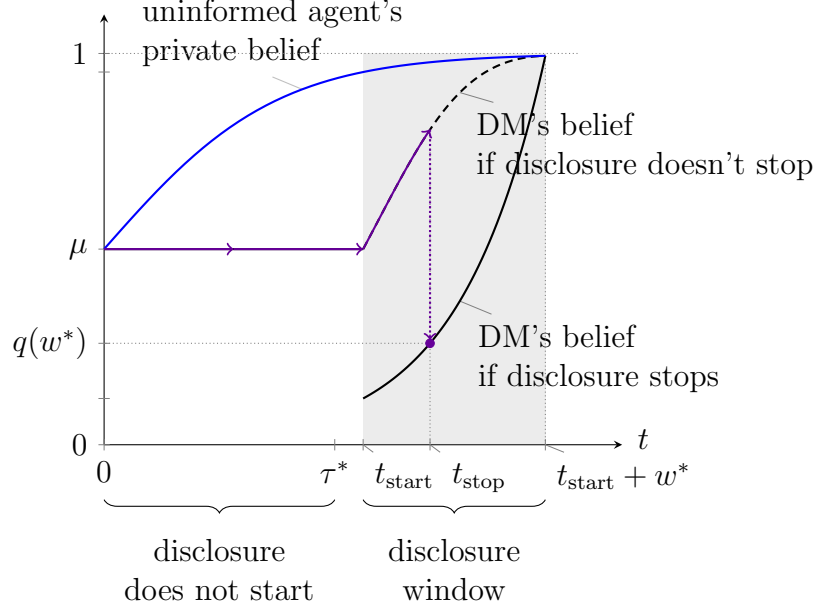


Figure 1: Agent's and decision maker's belief evolutions in an equilibrium with initial delay for  $\mu = 0.5$ ,  $r = 0.01$ ,  $\lambda = 5$ ,  $\alpha = 1$ ,  $\beta = 0.5$ .

Because signals are conclusive that the state is 0, the uninformed agent's posterior belief about  $\theta = 1$  increases over time in the absence of signals. The decision maker's belief about  $\theta = 1$  evolves according to the arrowed path. In this equilibrium, the two types of agent adopt the same starting strategy. The observation that disclosure does not start before  $\tau^*$  and starts after  $\tau^*$  is uninformative about the agent's type and therefore uninformative about the state. So the decision maker's (on-path) belief about the state is equal to her prior.

Suppose disclosure starts at time  $t_{\text{start}}$ . Along the history in which a signal does not arrive, disclosure lasts for a (maximum) duration of  $w^*$ .<sup>10</sup> The shaded region from time  $t_{\text{start}}$  to  $t_{\text{start}} + w^*$  is the *disclosure window* and  $w^*$  is the *length*, or the *duration*, of this disclosure window. During the disclosure window, not only is the evolution of the signal process informative of the state, the stopping of disclosure is bad news about

<sup>10</sup>More precisely, the agent can stop disclosure prematurely before  $w^*$ , or disclosure can terminate exogenously before  $w^*$ .

the agent’s private information prior to disclosure. In particular, only the informed agent intentionally stops within this window. Thus, “not stopping” is good news: the decision maker’s belief if disclosure does not stop increases over time, and drops down if disclosure stops. The decision maker’s posterior belief given the entire public history at the end of disclosure  $t_{\text{stop}}$  is  $q(w^*)$ , as illustrated in the figure.

I now analyze the equilibrium in the two stage games respectively. To better understand the dynamics of this game, it is more intuitive to start with the continuation stopping game given a starting time, and then work backwards to solve the initial starting game.

### 3.3 Stopping Game

The stopping game is a game of incomplete information in which at the beginning of the stopping game, the agent can be either informed or uninformed. Conceptually, the stopping game can be parameterized by the uninformed agent’s (private) belief that  $\theta = 1$ , denoted by  $\rho$ , and the decision maker’s belief that  $\theta = 1$  conditional on disclosure starting, denoted by  $\eta$ .<sup>11</sup> In this game, the decision maker cannot be more optimistic than the uninformed agent. That is,  $\rho \geq \eta$ . I characterize the equilibrium conditional on exogenous termination not occurring.<sup>12</sup>

In the stopping game, there are two types of (public) histories: a history along which there is a signal arrival and one where there is not. When a signal arrives at some time, it overrides information transmitted through all other channels. By [Lemma 1](#), the decision maker’s action is 0 at any stopping time after a signal. Because of discounting, the agent strictly prefers stopping at  $s$ . This is formalized in part (i) of [Theorem 1.B](#).

Along the history with no signal arrivals, the decision maker has no way of learning the state with certainty and the agent signals his type through the stopping time of disclosure. Because of the possibility of exogenous termination, the informed agent can disguise himself as an uninformed agent whose disclosure process has been exogenously terminated. This gives the uninformed agent incentives to delay stopping in an attempt to differentiate himself from the informed agent.

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<sup>11</sup>I characterize the equilibrium for any  $\rho \geq \eta$ . Both  $\rho$  and  $\eta$  are determined by the equilibrium starting time  $t_{\text{start}}$  in the initial starting game. Specifically,  $\rho = \rho(t_{\text{start}})$  where  $\rho(\cdot)$  is defined in [\(1\)](#). The decision maker’s belief is  $\eta = \eta(t_{\text{start}}) = \mu$ .

<sup>12</sup>Recall that the game ends when exogenous termination occurs.

To formalize this result, I first derive the decision maker's belief when disclosure stops. Because this is also the action the decision maker takes, it is a key element in determining the agent's equilibrium stopping strategies.

**Decision maker's (public) belief.** While the disclosure window is open, the decision maker updates her belief that  $\theta = 1$  through the evolution of the signal process and the observation of disclosure stopping. Let  $q(w)$  denote the decision maker's posterior belief about  $\theta = 1$  if disclosure stops at waiting time  $w$ . Given disclosure has started, the public history at  $w$  consists of the event that no signal arrives in  $[0, w]$ , and that disclosure stops at  $w$ . That is,

$$q(w) := \Pr(\theta = 1 | w_s > w, w_{\text{stop}} = w),$$

where  $w_s$  denotes the time of the first public signal arrival. Let  $F^\theta(w)$  denote the probability that disclosure stops within  $w$  conditional on state  $\theta$ , and  $f^\theta(w)$  its density whenever differentiable. Conditional on  $\theta = 1$ , the agent can only be uninformed. Disclosure stops when either the agent chooses to stop or termination arrives. That is,

$$f^1(w) = G'_U(w)e^{-\beta w} + \beta e^{-\beta w}(1 - G_U(w)). \quad (5)$$

To derive the rate at which disclosure stops at  $w$  conditional on  $\theta = 0$ , it is useful to first define the probability that the agent is informed at the beginning of the continuation game conditional on  $\theta = 0$ . Denote this probability by  $\gamma$ . Given  $\rho$  and  $\eta$ ,  $\gamma$  is given by  $\eta = \rho(1 - \gamma(1 - \eta))$ . By the same logic as the  $\theta = 1$  case, conditional on  $\theta = 0$ ,

$$f^0(w) = (1 - \gamma)f^1(w) + \gamma [G'_I(w)e^{-\beta w} + \beta e^{-\beta w}(1 - G_I(w))]. \quad (6)$$

By Bayes' rule,

$$q(w) = \frac{f^1(w)\eta}{f^1(w)\eta + e^{-\lambda w}f^0(w)(1 - \eta)}. \quad (7)$$

**Agent's expected payoff.** Given  $q(w)$ , the informed agent's expected payoff from waiting  $w$  to stop disclosing consists of three cases. The first case is when a signal arrives before termination arrives during the waiting time. The agent stops immediately and the decision maker takes action 0. The second case is when termination arrives at



some  $s$  before signal arrives during the waiting time. The decision maker takes action  $q(s)$ . The third case is when no signal arrival and no exogenous termination in  $w$ . The decision maker takes action  $q(w)$  at  $w$ .<sup>13</sup> Denote by  $V(w)$  the informed agent's expected payoff from waiting  $w$ , and  $U(w)$  the uninformed agent's.

$$V(w) = \int_0^w e^{-rs} \lambda e^{-\lambda s} e^{-\beta s} \kappa ds + \int_0^w e^{-rs} e^{-\lambda s} \beta e^{-\beta s} (\kappa + q(s)) ds + e^{-rw} e^{-\lambda w} e^{-\beta w} (\kappa + q(w)).$$

Similarly, the uninformed agent's expected payoff from waiting  $w$  is

$$U(w) = (1 - \rho)V(w) + \rho \left( e^{-rw} e^{-\beta w} (\kappa + q(w)) + \int_0^w e^{-rs} \beta e^{-\beta s} (\kappa + q(s)) ds \right).$$

It can be verified that if  $V(w)$  is (weakly) increasing in  $w$ , then  $U(w)$  is strictly increasing in  $w$ . Intuitively, conditional on  $\theta = 0$ , the longer disclosure is open, the more likely it is for a signal to arrive. The uninformed agent is more optimistic, so if the informed agent is (weakly) willing to wait, the uninformed agent must strictly prefer doing so.

Exploiting this property, I construct an equilibrium of the following form. Over an interval of waiting time  $[0, w^*]$ , the informed agent randomizes over waiting times in  $[0, w^*]$ , and the uninformed agent strictly prefers waiting till  $w^*$ . Both types stop with probability 1 by  $w^*$ . I then show that this is the unique equilibrium of the continuation game that survives the divinity refinement.

### 3.3.1 Equilibrium Dynamics

The most intuitive way to understand the equilibrium dynamics is through the decision maker's belief evolution. In equilibrium, the informed agent's randomization over stopping times feeds into the decision maker's belief evolution which in turn keeps the informed agent's expected payoff from stopping constant over time. Specifically,  $V'(w) = 0$  implies

$$q'(w) = r\kappa + (r + \lambda)q(w). \quad (8)$$

While the disclosure window is open, the informed agent discounts at an exponential rate and the signal arrival times are exponentially distributed. The informed agent's

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<sup>13</sup>The event that both a signal and termination arrive in a small interval  $[w, w + dw)$  is of order  $(dw)^2$  and can be neglected.

indifference condition (8) captures that the decision maker's belief when disclosure stops needs to counteract these two forces and increase exponentially.<sup>14</sup>

In this game, the decision maker's belief about the state is bounded above by the uninformed agent's at any point in time. This suggests  $q(w)$  cannot exponentially increase indefinitely and disclosure must stop before this belief exceeds the uninformed agent's. The following lemma takes this observation one step further and shows that at the end of the disclosure window, the decision maker's posterior belief that  $\theta = 1$  must equal the uninformed agent's.

**Lemma 2.** *If the uninformed agent's strategy is atomless with support  $[0, w^*]$ , then*

$$q(w^*) = \frac{\rho}{\rho + e^{-\lambda w^*}(1 - \rho)}. \quad (9)$$

Moreover,  $w^* < \infty$ .

At the end of the disclosure window, both types of agent stop disclosing with probability 1. Moreover, the informed agent stops continuously during the entire duration of the disclosure window. If disclosure stops at the end of the disclosure window, the decision maker infers that the agent must be uninformed, because the mass of informed agent who has not stopped at this point is zero, and thus stopping can only come from the uninformed agent. The decision maker's belief that  $\theta = 1$  therefore coincides with the uninformed agent's. As will show later, this construction is the unique equilibrium that survives the divinity refinement.

To further understand the equilibrium dynamics, consider the decision maker's belief before disclosure stops. Let  $q^C(w)$  denote the decision maker's belief given this history. That is,

$$q^C(w) := \Pr(\theta = 1 | w_s > w, w_{\text{stop}} \geq w).$$

Because only the informed agent voluntarily stops during the disclosure window,  $q^C(w)$  is increasing in  $w$  and  $q^C(w) > q(w)$  for all  $w < w^*$ .

In summary, from the decision maker's perspective, stopping prematurely before the disclosure window ends at  $w^*$  is bad news — whenever disclosure stops, the decision maker's belief drops from  $q^C(w)$  to  $q(w)$ . However, later premature stopping is good news — a longer duration without a signal arrival implies a higher probability that

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<sup>14</sup>Specifically, the solution to the first-order differential equation (8) is  $q(w) = me^{(r+\lambda)w} - \kappa r / (r + \lambda)$  with constant  $m > 0$  to be determined in equilibrium.

the state is good, and later stopping implies there's a higher chance that the agent is uninformed to begin with. **Figure 2** illustrates the dynamics by plotting the decision maker's beliefs as functions of waiting time  $w$ .

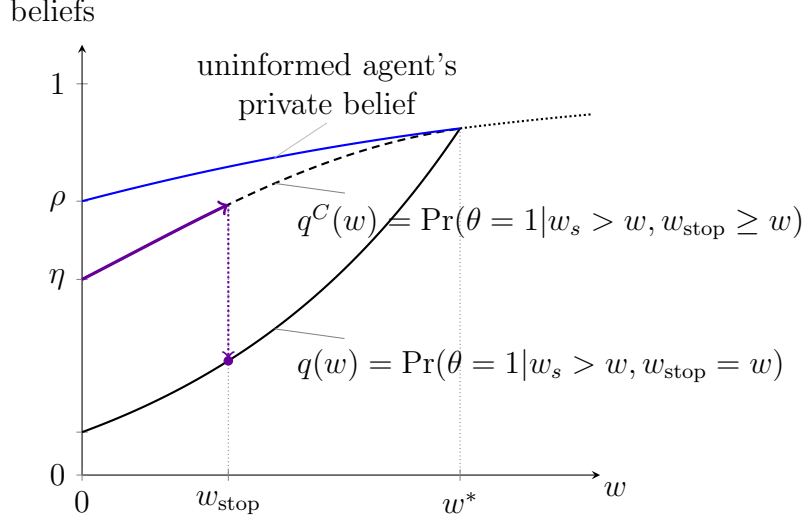


Figure 2: The decision maker's beliefs for  $\rho = 0.7$ ,  $\eta = \mu = 0.5$ ,  $\lambda = 3$ ,  $r = 0.5$ ,  $\alpha = 1$ ,  $\beta = 0.5$ , and  $\kappa = 1$ .

**Boundary value problem.** While the evolution of the decision maker's belief  $q(w)$  illustrates the equilibrium dynamics, it does not pin down the equilibrium strategies  $G_I(w)$ . Some properties of the agent's strategies get lost during their translation to beliefs. To pin down  $G_I(w)$ , first,  $G_I(w)$  is continuous at any  $w \in [0, w^*]$ . In particular,  $G_I(0) = 0$  and  $G_I(w^*) = 1$ . Together with **Lemma 2**, these observations imply  $G_I'(w^*) = 0$ . Equation (8) defines the second-order differential equation in  $G_I$ . All together, they form the boundary value problem stated in part (ii) of **Theorem 1.B**. By a shooting argument, this boundary value problem has a unique solution. **Figure 3** plots this solution,  $G_I(w)$ , and the uninformed stopping strategy,  $G_U(w)$ .

### 3.3.2 Divinity and Equilibrium Uniqueness

The following result establishes that the equilibrium characterized above is unique under divinity.

**Theorem 2.** *The equilibrium characterized in **Theorem 1.B** is the unique Markov perfect equilibrium of the continuation game that survives the divinity refinement.*

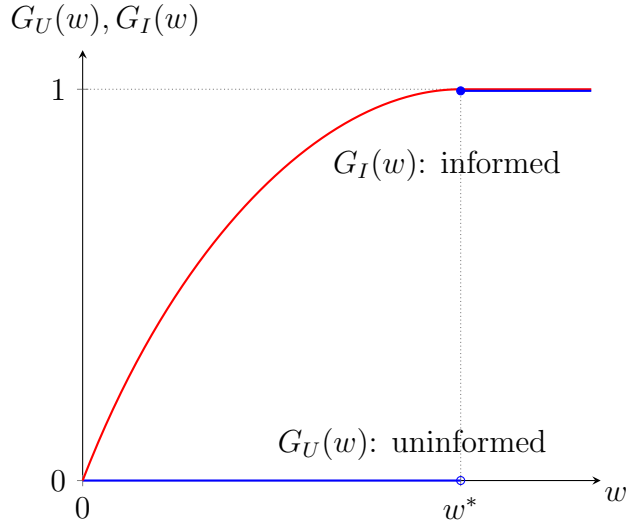


Figure 3: Agent's equilibrium strategies  $G_U(w)$  and  $G_I(w)$  for  $\rho = 0.7, \eta = 0.5, \lambda = 3, r = 0.5, \alpha = 1$ , and  $\beta = 0.5$ .

Given a fixed equilibrium, divinity specifies that the decision maker's off-path belief should assign zero weight to the agent being the type that is less likely to deviate. In this game, continuing disclosure after  $w^*$  is off the equilibrium path. Intuitively, for any given beliefs of the decision maker, the uninformed agent always has a stronger incentive to keep disclosure open. Therefore, the decision maker's off-path belief should assign zero weight to the agent being informed.

This means that the uninformed agent can always “prove” that he is uninformed by deviating to this off-path play. If the uninformed agent were ever to stop on the equilibrium path, it must be that whenever the uninformed agent chooses to stop, the decision maker's belief upon stopping is that the agent is uninformed. In turn, because posterior belief is a martingale, stopping at any  $w \geq w^*$  induces the same expected posterior belief/action. Because of discounting, the uninformed agent stops at  $w^*$ .

The above argument shows that in a divine equilibrium, the decision maker's belief that  $\theta = 1$  at  $w^*$  must be equal to the uninformed agent's. In addition, the decision maker's belief that  $\theta = 1$  must also be continuous at  $w^*$ : any jump in belief at  $w^*$  will result in a profitable deviation to stopping at  $w^*$  for the informed agent. These conditions pin down the boundary conditions of the boundary value problem, giving rise to equilibrium uniqueness. Without divinity, one can construct equilibria where disclosure stops after any amount of waiting time by imposing a punishing belief that

deters the agent from keeping the disclosure window open after said waiting time.<sup>15</sup>

### 3.3.3 Role of Information Asymmetry

Because the agent might be informed prior to starting disclosure, at the time disclosure starts, the decision maker's belief about the state is lower than the uninformed agent's. As it turns out, it is precisely this information asymmetry that enables information transmission in the stopping game.

To see this, suppose the agent is uninformed and the decision maker knows that. Because the posterior belief is a martingale, stopping at any time would induce the same expected action. Because of discounting, the agent will stop disclosing immediately and the decision maker takes an action that is equal to the common belief. Hence, the possibility that the agent is informed forces the uninformed agent to keep the disclosure window open in the hope that the lack of signals corroborates that he is uninformed, enabling information transmission. The following lemma formalizes this result.

**Proposition 1.**  *$w^* > 0$  if and only if  $\rho > \eta$ .*

In some sense, the agent does not care about what he knows but cares about what the decision maker believes. The uninformed agent is more optimistic than the decision maker, and his incentive to delay and let information flow is not due to learning for himself. Instead, he delays so that the decision maker can learn and become as optimistic as he is.

**Comparative statics.** From the above discussion, it seems intuitive that the larger the information asymmetry at the start of disclosure is, the longer it takes to weed it out. This suggests that the waiting time should increase in the magnitude of information asymmetry. The following result formalizes this intuition.

**Lemma 3.** *The equilibrium waiting time  $w^*$  is increasing in  $\rho$  and decreasing in  $\eta$ .*

Although intuitive, technically  $w^*$  is part of a boundary value problem and is pinned down in equilibrium through the informed agent's randomization, so proving [Lemma 3](#) is not straightforward. Nevertheless, this result is crucial in analyzing the starting game in [Section 3.4](#) and deriving the main insight of the paper in [Section 4](#). The analysis so

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<sup>15</sup>More precisely, with a punishing belief, one can construct equilibria that “ends early” by having a mass of informed agent stopping at the end of the disclosure window.

far has demonstrated that the degree of information asymmetry at the beginning of the disclosure window impacts the duration of the disclosure window. [Section 4](#) concerns how this degree of information asymmetry is affected by the time disclosure starts. On that note, I now turn to analyzing the agent’s optimal time to start disclosure.

### 3.4 Starting Game

In the initial starting game, the agent chooses a time to start disclosure, knowing that this starting time induces the duration he keeps the disclosure window open, given by the (unique) equilibrium in the continuation stopping game.

Unlike the stopping game where any signal arrival is public information, the agent’s learning is private prior to the start of disclosure. If the agent delays starting and a signal arrives, the agent is able to conceal this information from the decision maker, and behave optimally as an informed agent onward. Had the agent not delayed, the decision maker would have seen this signal and taken action 0. On the other hand, delay in the start of disclosure translates to a delay in the expected time till payoff realizes, which incurs a cost due to discounting.<sup>16</sup>

If the agent is impatient relative to the value of information, he starts disclosing as soon as he gets the opportunity. Otherwise, he delays to privately learn for a certain amount of time before starting. I provide sufficient conditions under which starting immediately is an equilibrium, and sufficient conditions under which delaying is an equilibrium whenever starting immediately is not.<sup>17</sup>

To simplify the exposition, I impose the following assumption.

**Assumption.** *Assume the prior about  $\theta = 1$  is  $\mu \geq 1/2$ .*

This assumption plays no role in the stopping game, but it simplifies the analysis in the starting game and delivers a clean intuition.

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<sup>16</sup>More precisely, suppose the decision maker’s belief does not change no matter when disclosure starts. Prior to the start of disclosure, the (uninformed) agent becomes optimistic. The information asymmetry is larger and, as implied by [Lemma 3](#), the (uninformed) agent needs to keep the disclosure window open longer in the continuation game.

<sup>17</sup>I focus on the incentive of an agent who has the opportunity to disclose at time 0. An agent who got the opportunity at later time has the same incentives. Details of this argument are in [Proof of Theorem 1.A](#) in the appendix.

### 3.4.1 Immediate Disclosure Equilibrium

The following proposition provides sufficient conditions under which it is an equilibrium for both types of the agent to start disclosing as soon as he gets an opportunity. I refer to this equilibrium as the *immediate disclosure equilibrium*.

**Proposition 2.** *If*

$$\frac{r}{\lambda} \geq \frac{(1 - \mu)\mu}{\kappa + \mu}, \quad (10)$$

*then immediate disclosure is an equilibrium.*

To interpret condition (10), consider a scenario in which whenever disclosure starts, it stops immediately and the decision maker believes that the agent is uninformed. This is the best case scenario for both types of agent — the decision maker takes the highest possible action and the agent does not need to engage in any waiting to induce it.

Condition (10) can be rearranged as  $\lambda(1 - \mu)\mu \leq r(\kappa + \mu)$ . The left-hand side,  $\lambda(1 - \mu)\mu$ , is the marginal benefit from delaying in this best case scenario. At time 0, with rate  $\lambda(1 - \mu)$ , a signal arrives. By delaying for an infinitesimal amount of time, the agent learns that the state is  $\theta = 0$  but the decision maker does not. The agent then immediately stops and gets payoff  $\kappa + \mu$ . If he had not delayed and started disclosing right away, he would have gotten payoff  $\kappa + 0$ . The right-hand-side,  $r(\kappa + \mu)$ , is the marginal cost from delaying. Because there is no waiting in the continuation game, the cost purely comes from discounting.

Therefore, condition (10) implies that, in the best case scenario where the agent does not need to wait in the continuation game, discounting ( $r$ ) is so large relative to information ( $\lambda$ ) that the agent does not want to delay starting at any point in time.<sup>18</sup> Thus, in the case where the agent does have to wait in the continuation game and have to wait even longer if he starts later, the agent would not want to delay.

### 3.4.2 Delayed Equilibrium

In a delayed equilibrium, neither type of agent starts disclosure until some  $\tau^* > 0$ . Then both start immediately at and after  $\tau^*$ . That is, if an agent already has the opportunity before  $\tau^*$ , they start disclosing immediately at  $\tau^*$ , otherwise they start disclosing as

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<sup>18</sup>More precisely, condition (10) implies that the agent does not want delay at  $t = 0$ . For  $t > 0$ , a similar condition can be obtained by replacing  $\mu$  on the right-hand side with the uninformed agent's belief  $\rho(t)$ . Condition (10) implies the same inequality holds with  $\rho(t)$  for all  $t > 0$ .

soon as they receive the opportunity. By the above argument, if immediate disclosure is not an equilibrium, then there must exist a point in time where the value of private learning is large relative to discounting. By the assumption  $\mu \geq 1/2$ , this value of private learning diminishes as time goes by, and will eventually be overwhelmed by discounting. This means that if an equilibrium prescribes immediate disclosure after some time  $\tau^*$ , this  $\tau^*$  needs to be large enough until the discounting effects dominates.

On the other hand,  $\tau^*$  cannot be too large. Otherwise the (informed) agent would rather deviate to starting disclosure right away and getting action 0 (as the decision maker's off-path belief is 0), than waiting till  $\tau^*$  for the chance of inducing a higher action. The following proposition provides sufficient conditions for the existence of a  $\tau^*$  that strike a balance between these two forces.

**Proposition 3.** *Fix parameters such that immediate disclosure is not an equilibrium. There exists  $0 < \bar{\kappa} \leq (\lambda/r)(1 - \mu)\mu - \mu$  such that for all  $\kappa \leq \bar{\kappa}$ , there exists  $\underline{\tau}^*(\kappa) > 0$  such that it is an equilibrium for neither type of agent to start disclosing for  $t < \underline{\tau}^*(\kappa)$ , and both types of agent to start disclosing as soon as an opportunity arrives for  $t \geq \underline{\tau}^*(\kappa)$ . The decision maker's belief about  $\theta = 1$  if disclosure starts off-path at  $t < \underline{\tau}^*(\kappa)$  is 0.*

The key is the additive constant  $\kappa$  in the agent's payoff being small. Intuitively, in the stopping equilibrium analyzed in [Section 3.4](#), because of exogenous termination, it is always possible that stopping is due to an uninformed agent getting terminated. So in the absence of signals, the decision maker's belief when disclosure stops is strictly positive. This means if the agent follows the equilibrium path and waits till  $\tau^*$  to start disclosure, his on-path expected action is strictly positive. So if  $\kappa$  is small, the agent (both types, informed in particular) would prefer waiting to induce a strictly positive action, than getting the zero action right away.

### 3.4.3 Divinity and Equilibrium Multiplicity

The immediate disclosure equilibrium survives the divinity refinement trivially because there are no off-path actions. For the delayed equilibrium, starting disclosure before  $\tau^*$  is off the equilibrium path and the decision maker's off-path belief about  $\theta = 1$  is zero. Is this punishing off-path belief consistent with the divinity refinement?

As discussed in the stopping game in [Section 3.3](#), the divinity refinement specifies that the decision maker's off-path belief should assign zero weight to the type of agent



that has less incentive to deviate. The zero off-path belief assigns zero weight to the uninformed agent. In other words, if disclosure starts before  $\tau^*$ , the decision maker thinks that it is the informed agent who has deviated, and thus believes that  $\theta = 0$ . For this to be consistent with divinity, at each  $t < \tau^*$ , for any decision maker's belief  $\eta \in [0, \rho(t)]$  such that the uninformed agent finds it (at least weakly) profitable to deviate to starting at  $t$ , the informed agent must find it strictly profitable to deviate. In other words, the set of decision maker's beliefs that induce a profitable deviation for the uninformed agent must be a proper subset of that for the informed agent.

Whether this condition is satisfied in equilibrium depends on the parameters. **Figure 4** plots two numerical examples, both of which satisfy the sufficient condition in **Proposition 3** and thus are equilibria. The picture on the left is an example where the equilibrium is divine, the one on the right is not. The red (solid) area plots the set of decision maker's belief  $\eta$  such that the informed agent finds it profitable to deviate, and the blue (patterned) area is where the uninformed agent finds profitable to deviate. To satisfy divinity, the blue set needs to be entirely contained in the red.

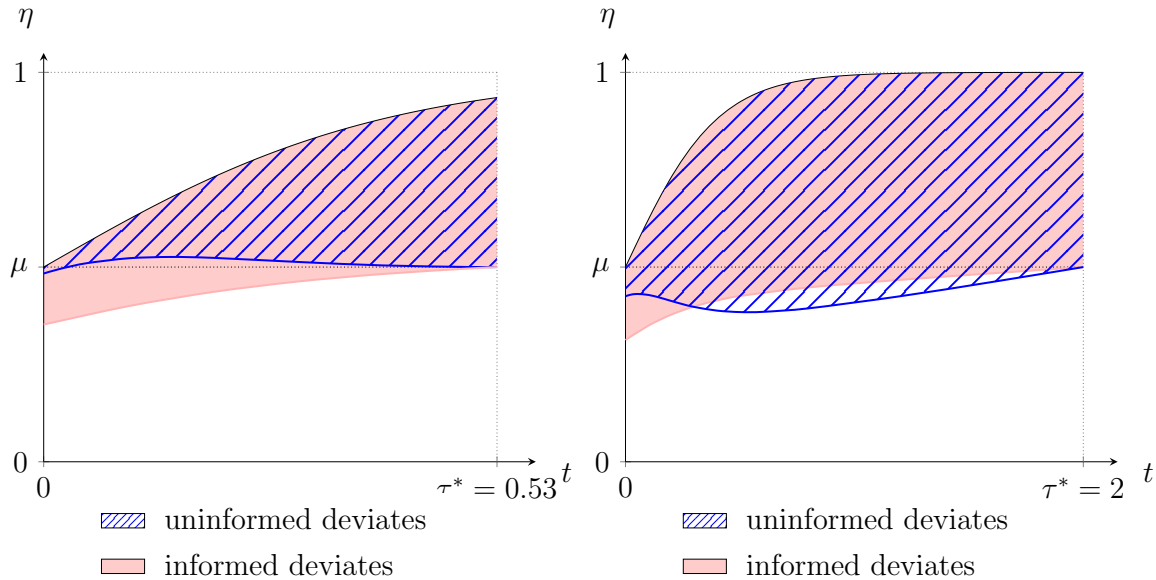


Figure 4: Numerical examples where a delayed equilibrium is divine (left panel,  $\tau^* = 0.53$ ) and is not (right panel,  $\tau^* = 2$ ). Parameters are  $\mu = 0.5, r = 0.01, \lambda = 5, \alpha = 1, \beta = 0.5$ , and  $\kappa = 1$ .

In general, the initial starting game will have multiple equilibria. Within the class of pooling equilibria characterized here, there typically exists a continuum of  $\tau^*$ 's that

can be sustained as an equilibrium and survives the divinity refinement. The numerical example above shows that the divinity refinement can indeed eliminate some equilibria, but in general, it cannot reduce the equilibrium set to a singleton.

## 4 Duration of Disclosure Windows

The equilibrium features a novel dynamic between the start disclosing time and the stop disclosing time: delay in the start of disclosure leads to a longer disclosure window.

**Proposition 4** formalizes this result and **Figure 5** illustrates.

**Proposition 4.** *The agent's waiting time  $w^*(\tau)$  is increasing in the disclosure starting time  $\tau$ . Moreover, there exists  $\bar{w}^* < \infty$  such that  $\lim_{\tau \rightarrow \infty} w^*(\tau) = \bar{w}^*$ .*

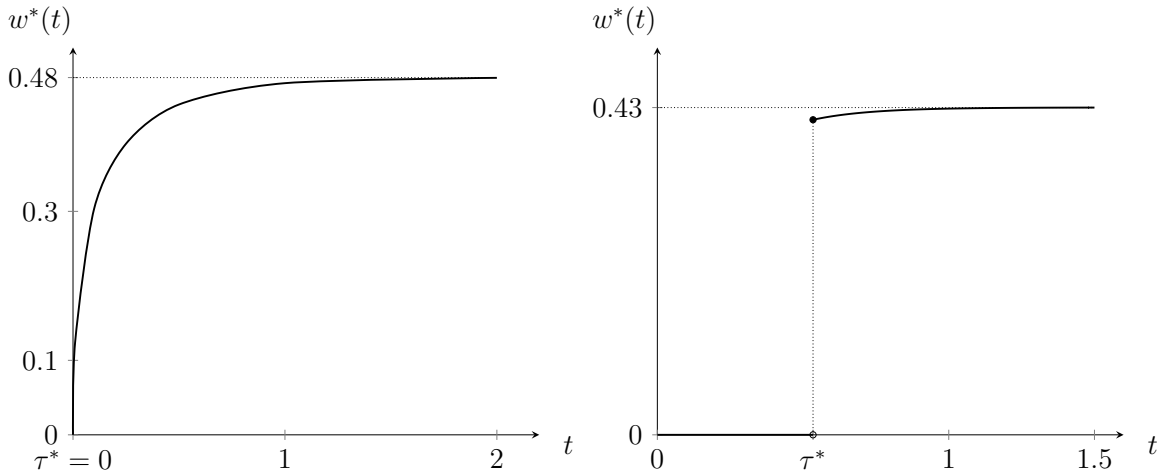


Figure 5: Agent's waiting time  $w^*(t)$  as a function of the disclosure starting time  $t$ . Left panel:  $\tau^* = 0$ ;  $\mu = 0.5$ ,  $r = 0.5$ ,  $\lambda = 3$ ,  $\alpha = 1$ ,  $\beta = 0.5$ , and  $\kappa = 1$ . Right panel:  $\tau^* = 0.53$ ;  $\mu = 0.5$ ,  $r = 0.01$ ,  $\lambda = 5$ ,  $\alpha = 1$ ,  $\beta = 0.5$ , and  $\kappa = 1$ .

The agent and the decision maker start off with the same information about the state, and become increasingly asymmetrically informed while the start of disclosure is delayed. During this delay, the agent privately learns about the state through the information process. He either becomes more optimistic in the absence of signals or becomes informed whenever a signal arrives. The decision maker on the other hand, does not get any information about the state: she does not observe the information process, nor can she infer anything from the agent's behavior because both types of the agent

adopt the same starting strategy. So on the equilibrium path, the decision maker's belief about the state stays the same as her prior.<sup>19</sup> The longer the start of disclosure is delayed, the more divergent the agent's and the decision maker's beliefs become. In the continuation stopping game, the (uninformed) agent keeps the disclosure window open until the decision maker's belief catches up to his own. So the uninformed agent needs to keep the disclosure window open longer to reduce the now-larger information asymmetry between him and the decision maker.

With time, the agent becomes more and more certain of the state. If disclosure starts late in time, the continuation game approaches to a benchmark case in which the agent knows whether the state is 0 or 1. Let  $\bar{w}^*$  denote the optimal waiting time in this benchmark case. The waiting time  $w^*(t)$  then converges to  $\bar{w}^*$  as  $t$  increases. In the next section, I present this benchmark model and characterize  $\bar{w}^*$ .

## 5 Benchmarks and Extensions

### 5.1 Perfectly Informed Agent

As a benchmark, consider the scenario in which the agent is informed of whether the state is  $\theta = 0$  or  $\theta = 1$  at time 0. As the start of disclosure increases, the game approximates this benchmark case where the agent is perfectly informed. As mentioned in [Proposition 4](#), the waiting time in the continuation stopping game is bounded above by  $\bar{w}^*$ , which is the waiting time in this benchmark. [Proposition 5](#) formalizes this argument (the characterization of  $\bar{w}^*$  is related to the [Appendix](#)).

**Proposition 5.** *In the continuation game, there exists  $0 < \bar{w}^* < \infty$  such that the informed agent randomizes over stopping times in  $[0, \bar{w}^*]$  and uninformed agent stops with probability 1 at  $\bar{w}^*$ . (The equilibrium is similarly characterized as in [Theorem 1.B](#)).*

### 5.2 Decision-Maker-Optimal Disclosure Duration

The disclosure protocol studied in this paper features the agent controlling both the start and the stop of the disclosure window. The resulting disclosure duration is what's

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<sup>19</sup>While the decision maker's belief about the state does not change, her belief about the agent's type changes. The probability that the agent is informed increases as time goes by, but if the agent remains uninformed, his belief also increases. The decision maker's belief about the state takes expectations of these two beliefs and stays constant at the prior on average.

optimal for the agent. What is the optimal disclosure duration for the decision maker?

In what follows, I study a model in which the decision maker chooses the stopping time of disclosure in addition to the action taken at the end of disclosure. This model captures that the (uninformed) agent's incentive to keep disclosure open differs from the decision maker's.

Same as the main model, the decision maker can stop and therefore take an action if and only if disclosure has started at some time prior. The rest of the setup remains the same except the exogenous termination is now irrelevant and thus eliminated.<sup>20</sup>

In this model, the decision maker's problem is Markov in her belief. She either stops when she sees a signal and thus learns the state is 0, or she waits until her belief reaches a threshold  $\bar{\eta}$  that is independent of the time at which disclosure started. As before, denote the decision maker's belief at the beginning of the continuation game by  $\eta$ . The following conjecture formalizes this intuition.

**Proposition 6.** *There exists  $\underline{\eta}$  and  $\bar{\eta}$  with  $0 < \underline{\eta} < \bar{\eta} < 1$  such that if  $\eta < \underline{\eta}$  or  $\eta \geq \bar{\eta}$ , the decision maker stops immediately. If  $\eta \in [\underline{\eta}, \bar{\eta})$ , the decision maker either stops at the first time her posterior belief is equal to 0 or the first time her posterior belief reaches  $\bar{\eta}$ .*

**Figure 6** plots the optimal time that the decision maker waits before taking an action as a function of her initial belief  $\eta$  at the beginning of the stopping game. the closer the decision maker's initial belief is to the target belief  $\bar{\eta}$ , the less time it takes for her belief to increase to  $\bar{\eta}$ .

The decision maker's and the agent's incentives to delay in the stopping game differ. The decision maker wants to take an action that matches the state. Her incentive to delay stopping is driven by learning: the later she stops, the more she learns about the state and is thus able to take a more informative action. This is in contrast to the (uninformed) agent's incentive to delay stopping in the main model. The agent wants the decision maker to take a high action regardless of the state. Although the uninformed agent wants the decision maker to learn, he cares asymmetrically about the direction in which the decision maker learns. The uninformed agent cares about learning only to the extent of getting the decision maker to believe the way he does.

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<sup>20</sup>The purpose of exogenous termination is to introduce noise so that the decision maker does not know whether the end of disclosure is by the agent's choice or exogenous. This noise is irrelevant here because the decision maker is choosing the stopping time.

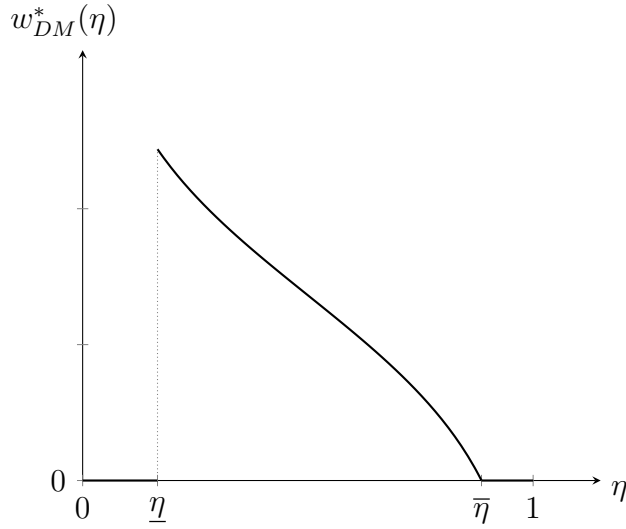


Figure 6: Decision maker's equilibrium waiting time  $w_{DM}^*(\eta)$  for  $\mu = 0.5, r = 0.5, \lambda = 5$ , and  $\alpha = 1$ .

## A Appendix

[This section is incomplete. Please click [here](#) for the latest version.]

### A.1 Proofs for **Section 3**

#### A.1.1 Proof of **Lemma 1**

Given any public history  $h_T^{\text{pub}}$  at  $T$ , denote  $\Pr(\theta = 1 | h_T^{\text{pub}}) = q(T)$ . The decision maker's problem is  $\max_{a \in \mathbb{R}} \mathbb{E} \left[ e^{-rT} (1 - (a - \theta)^2) | h_T^{\text{pub}} \right]$ , which is equal to

$$\max_{a \in \mathbb{R}} \left( e^{-rT} (1 - (a - 0)^2) \right) (1 - q(T)) + \left( e^{-rT} (1 - (a - 1)^2) \right) q(T)$$

Setting the derivative with respect to  $a$  to 0 results in  $a = q(T)$ .

#### A.1.2 Proof of **Theorem 1.B (i)**

Suppose a signal arrives at  $\hat{w} > 0$ . By Bayes' rule, both the agent and the decision maker's belief is zero for all  $w \geq \hat{w}$ . By **Lemma 1**, the decision maker takes action 0 if disclosure stops at any  $w \geq \hat{w}$ . The agent's expected payoff from stopping at any  $w \geq \hat{w}$  (from the perspective of  $\hat{w}$ ) is  $e^{-r(w-\hat{w})}\kappa$ , which is maximized at  $\hat{w}$ .

### A.1.3 Proof of Proposition 1

By definition,  $w^* \geq 0$  and  $\rho \geq \eta$ . Proving Proposition 1 is equivalent to showing  $w^* = 0$  if and only if  $\rho = \eta$ . Fix  $\rho = \eta$ . The uninformed agent's expected payoff from waiting  $w \geq 0$  to disclose is

$$\begin{aligned} V_U(w) = & e^{-\beta w} (\rho + e^{-\lambda w}(1 - \rho)) e^{-rw} \left( \kappa + \frac{\rho}{\rho + e^{-\lambda w}(1 - \rho)} \right) \\ & + e^{-\beta w}(1 - \rho) \int_0^w \lambda e^{-\lambda s} e^{-rs} \kappa ds \\ & + \int_0^w \beta e^{-\beta \tau} (\rho + e^{-\lambda \tau}(1 - \rho)) e^{-r\tau} \left( \kappa + \frac{\rho}{\rho + e^{-\lambda \tau}(1 - \rho)} \right) d\tau \\ & + \int_0^w \beta e^{-\beta \tau} \left( (1 - \rho) \int_0^\tau \lambda e^{-\lambda s} e^{-rs} \kappa ds \right) d\tau. \end{aligned}$$

It can be readily verified that  $V_U(w)$  is strictly decreasing in  $w$  for all  $w \geq 0$  and therefore maximized at  $w = 0$ . The same calculation and conclusion apply to the informed agent.

### A.1.4 Proof of Theorem 1.A

The conditions under which  $\tau^* \geq 0$  exists are stated in Proposition 2 and Proposition 3. The proofs of these two results are below.

### Preliminaries

Let  $V^*(t)$  and  $U^*(t)$  denote the equilibrium payoffs of the informed and uninformed agent's in the continuation game. Suppose  $\eta(t) = \mu$  for all  $t \geq 0$ . Suppose the agent is uninformed at  $t = 0$  and has the opportunity to disclose at  $t = 0$ . His expected payoff from waiting till  $t$  to start disclosing if he remains uninformed at  $t$  and starting immediately if he becomes informed is

$$Y(t) = (1 - \mu) \int_0^t \lambda e^{-\lambda s} e^{-rs} V^*(s) ds + ((1 - \mu)e^{-\lambda t} + \mu) e^{-rt} U^*(t).$$

The derivative of  $Y$  with respect to  $t$  is proportional to  $y(t)$  where  $y(t)$  is defined as

$$y(t) := \lambda(1 - \rho(t))(V^*(t) - U^*(t)) + U^{*'}(t) - rU^*(t).$$

After some simplifying,

$$y(t) = \rho'(t) \left( (1 - \rho) \frac{\partial \hat{V}}{\partial \rho} + \rho \frac{\partial \hat{U}_1}{\partial \rho} \right) + \left( (1 - \rho) \frac{\partial \hat{V}}{\partial w^*} + \rho \frac{\partial \hat{U}_1}{\partial w^*} \right) w^*(t) - rU^*(t). \quad (11)$$

Similarly, define the informed agent's expected payoff from starting at  $t$  as

$$Z(t) = e^{-rt} V^*(t).$$

The derivative is proportional to

$$z(t) = V^*(t) - rV^*(t).$$

#### A.1.5 Proof of **Proposition 3**

For a fixed  $\kappa$ , if the proposed strategies under  $\underline{\tau}^*(\kappa)$  are (part of) an equilibrium, the following must be true. First, the uninformed agent's expected payoff from starting at  $t$ ,  $\Pi_U(t)$ , and the informed agent's expected payoff from starting at  $t$ ,  $\Pi_I(t)$ , must be decreasing for all  $t \geq \underline{\tau}^*(\kappa)$ . Second, neither the uninformed nor the informed agent wants to deviate to starting before  $\underline{\tau}^*(\kappa)$ . The goal is to derive sufficient conditions under which there exists  $\underline{\tau}^*(\kappa)$  such that both statements hold.

**Lemma 4.** *Fix parameters such that immediate disclosure is not an equilibrium. There exists  $\underline{\tau}^*(\kappa) > 0$  such that  $\Pi_U(t)$  and  $\Pi_I(t)$  are both decreasing in  $t$  for all  $t \geq \underline{\tau}^*(\kappa)$ .*

*Proof.* If immediate disclosure is not an equilibrium, by contrapositive of **Proposition 2**, condition (10) does not hold. That is, Fix  $\kappa$  such that

$$\kappa < (\lambda/r)(1 - \mu)\mu - \mu. \quad (12)$$

In this case,  $y_0(t)$  is still (strictly) decreasing in  $t$  for all  $t \geq 0$  - the condition that implies  $y_0(t)$  is decreasing is  $\frac{r}{\lambda} \geq 1 - 2\mu$ , which always holds by assumption  $\mu \geq 1/2$ . However, if (10) does not hold,  $y_0(0) > 0$ . Because  $y_0(t)$  is continuous in  $t$ , and  $\lim_{t \rightarrow \infty} y_0(t) = \lim_{t \rightarrow \infty} \rho'(t) - r(\kappa + \rho(t)) = -r(\kappa + 1) < 0$ , there exists a  $\tau_0(\kappa)$  where  $0 < \tau_0(\kappa) < \infty$  such that  $y_0(\tau_0(\kappa)) = 0$  and  $y_0(t) < 0$  for all  $t > \tau_0(\kappa)$ . Moreover,  $\tau_0(\kappa)$  is unique because  $y_0(t)$  is strictly decreasing in  $t$ . We have shown that  $y_0(t) \leq 0$  implies  $y(t) < 0$ . So  $y(t) < 0$  for all  $t \geq \tau_0(\kappa)$ .

If immediate disclosure is not an equilibrium, there must exist some  $t \geq 0$  such that  $y(t) > 0$ . Because  $y(t)$  is continuous in  $t$ , there exists  $\underline{\tau}^*(\kappa) > 0$  with  $\underline{\tau}^*(\kappa) < \tau_0(\kappa)$  such that  $y(\underline{\tau}^*(\kappa)) = 0$ .  $\square$

Next, I derive conditions on  $\kappa$  such that neither the uninformed nor the informed agent wants to deviate to starting before  $\underline{\tau}^*(\kappa)$ .

**Lemma 5.** *There exists  $0 < \bar{\kappa} \leq (\lambda/r)(1 - \mu)\mu - \mu$  such that for all  $\kappa < \bar{\kappa}$ ,*

$$e^{-r\underline{\tau}^*(\kappa)}V^*(\underline{\tau}^*(\kappa)) \geq \kappa.$$

*Proof.* Recall that the informed agent is indifferent with respect to waiting times in  $[0, w^*]$  in the continuation game. So for any starting time  $\tau$ ,  $V^*(\tau) = \kappa + q(0, \tau)$ . So if the informed agent does not want to deviate to starting before some  $\tau$ , it must be that  $e^{-r\tau}(\kappa + q(0, \tau)) \geq \kappa$ , which is equivalent to  $q(0, \tau) \geq \kappa(e^{r\tau} - 1)$ . The goal is to show

$$q(0, \underline{\tau}^*(\kappa)) \geq \kappa(e^{r\underline{\tau}^*(\kappa)} - 1). \quad (13)$$

Recall the definition of  $\tau_0(\kappa)$  from the proof of the previous lemma:  $\tau_0(\kappa)$  is such that  $y_0(\tau_0(\kappa)) = 0$ , that is

$$\lambda(1 - \rho(\tau_0(\kappa)))\rho(\tau_0(\kappa)) - r(\kappa + \rho(\tau_0(\kappa))) = 0.$$

Consider  $\kappa = 0$ . Because  $\rho(\cdot) > \mu > 0$ , the above equality implies  $\tau_0(0) < \infty$ . Then  $\underline{\tau}^*(0) < \tau_0(0) < \infty$ . Because  $\kappa(e^{r\underline{\tau}^*(\kappa)} - 1)$  is continuous in  $\kappa$ , as  $\kappa \rightarrow 0$ ,  $\kappa(e^{r\underline{\tau}^*(\kappa)} - 1) \rightarrow 0$ . Because in equilibrium, stopping disclosure is always on the equilibrium path and with strictly positive probability, the stopping comes from an uninformed agent who got terminated, so  $q(0, \underline{\tau}^*(\kappa)) > 0$  for all  $\kappa \geq 0$ . Therefore, the inequality (13) holds strictly at  $\kappa = 0$ . Because both  $q(0, \underline{\tau}^*(\kappa))$  and the right-hand side of (13) are continuous in  $\kappa$ , there exists a neighborhood of 0 such that  $q(0, \underline{\tau}^*(\kappa)) > \kappa(e^{r\underline{\tau}^*(\kappa)} - 1)$ .

Consider the solutions to  $q(0, \underline{\tau}^*(\kappa)) = \kappa(e^{r\underline{\tau}^*(\kappa)} - 1)$ . If there exists solutions to this equation, define  $\bar{\kappa}$  to be the smallest solution, so for all  $\kappa < \bar{\kappa}$ ,  $q(0, \underline{\tau}^*(\kappa)) > \kappa(e^{r\underline{\tau}^*(\kappa)} - 1)$ . If there does not exist a solution, this means for all  $\kappa \in [0, (\lambda/r)(1 - \mu)\mu - \mu]$ ,  $q(0, \underline{\tau}^*(\kappa)) > \kappa(e^{r\underline{\tau}^*(\kappa)} - 1)$ . In this case, define  $\bar{\kappa} = (\lambda/r)(1 - \mu)\mu - \mu$ . The result follows.  $\square$



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