# Persuading to Participate: Coordination on a Standard*

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**Abstract**

We study coordination among competitors in the shadow of a market mechanism. Our main example is standard setting: either firms coordinate through a standard-setting organization (SSO), or a market solution—a standards war—emerges. A firm's veto to participate in the SSO triggers a standards war. Participation constraints are demanding, and the optimal SSO can involve on-path vetoes. We show that vetoes are effectively deterred if firms can (partially) release their private information to the public. We discuss several business practices that can serve as a signaling device to provide that information and to effectively ensure coordination.

*JEL codes:* L24, D83, O32, D21

*Keywords:* innovation, standard-setting organizations, patents, persuasion, coordination

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# 1 Introduction

The road to the standard for high-resolution home-video discs (DVDs) was not straight. After a first attempt to coordinate on a standard (in 1994) failed, two rival technologies were developed: the MultiMedia Compact Disc (MMCD) by Sony and Philips and the Super Density (SD) disc by Toshiba and Time Warner. Although the movie industry was pushing for a unified standard, no cooperation was in sight and a standards war seemed inevitable.[1]

Why did the two camps at first refuse to cooperate? One explanation is that they had private information about their prospects in a standards war. As a result, both may have been optimistic that their technology would prevail in the market and thus refused to concede. Alternatively, and more strikingly, both parties may have been optimistic despite holding a common prior.

Mutual optimism occurs if both parties receive a positive signal about their own capabilities in a standards war. But they are less optimistic about their competitor's expected capabilities. When evaluating their strategic options, both parties put little weight on the possibility of facing a strong competitor. Mutual optimism implies that each party expects a favorable outcome. Yet a standard-setting organization (SSO) can at most grant a favorable outcome to one of them. So a strong firm has an incentive to refuse to participate in an SSO.

In the case of the DVD standard, both camps were optimistic. The MMCD camp was convinced that without the patents it held on the compact disc (CD), no successful implementation of a video disc was possible. The SD camp, meanwhile, was convinced that its dual-layer technology advanced far beyond anything based on CD technology (see Taylor, 2001, ch. 2).

According to industry observers, a group of technicians from the leading computer companies (known as the technical working group, or TWG) played a major role in persuading both camps to form the DVD Consortium (later the DVD Forum). In June 1995 Sony executive Norio Ohga shared his view that a standards war was unavoidable (see Taylor, 2001, ch.2). As the camps prepared for a standards war, the TWG announced that it was going to analyze the two camps' proposals.[2] Shortly thereafter, both camps announced that they would work together. And in fact they finally united in the DVD Consortium.

Why did the announcement by the TWG induce the camps to cooperate? The message contained no information about whom the TWG would side with. Instead, two other aspects of it were important. First, the announcement was credible. As Toshiba executive Koji Hase later put it, TWG chairman Alan Bell "is fair, he's very fair. He did not side

[1] For a detailed timeline and further information, see Taylor (2001) and Wolpin (2007). For the view of industry observers on the verge of the standards war, see, for example, Variety (1995).

[2] See, for example, their press release at `https://tech-insider.org/digital-video/research/1995/0503.html`.

with Toshiba [or] Sony for that matter. He tried to be as fair as possible."[3] Second, the announcement implied that the TWG was going to release the outcome of its evaluation at a later date (see Wolpin, 2007).

The TWG was committed to releasing information about the technologies if the parties could not find a solution on their own. That commitment overcame the coordination failure that resulted from mutual optimism. The TWG did not interfere with the formal rules governing how the firms would compete in the market if they could not agree on a standard (the market solution). Instead, it influenced the structure of expected information. Moreover, it did so by announcing its plans to send a signal rather than actually sending a signal.[4]

Most industries operating in two-sided markets coordinate on a de facto standard eventually. A standard is a platform that governs firms' interaction. If a standard is not imposed by a regulator, there are, broadly speaking, two ways industries can set their standard. Firms can cooperate via an SSO, or market forces can determine the outcome. In the former case, the SSO implements the standard. In the latter case, the standard emerges as the outcome of a standards war.[5]

In this paper, we model the market solution as a game of incomplete information. An SSO is the alternative to the market. It determines the standard outside the market. An SSO can only be established if firms agree to form one.

We address the question: is there a simple and cost-effective way to foster coordination? Our answer is yes, provided firms have access to a certain signaling device. The most important feature of that signaling device is that it can conceal information for some time before releasing it. We construct the optimal signaling device. It has two realizations per firm. We refer to it as *informational punishment*.

Informational punishment has a variety of desirable features: (i) in equilibrium revealing private information is only a threat (that is, the threat is executed with probability 0); (ii) informational punishment has no effect on firms' incentive constraints conditional on acceptance; (iii) a decentralized implementation is possible (that is, firms can design informational punishments themselves); and (iv) the punishment does not require enforcement by a third party but rather results from the complying firms' competitive market behavior.

Our stylized model of the standard-setting process is inspired by the DVD case. Two firms are on the verge of a standards war. A third party collects information from firms and promises to release (some of) the information if coordination fails. We construct the optimal information-revelation device and show how it facilitates coordination on a

[3] Quote taken from Wolpin (2007).

[4] The amount of information the TWG could use to produce that signal was controlled by the firms themselves. Prior to its announcement that it would investigate the quality of the firms' proposed standards, the TWG would need to gather information from the firms.

[5] Other examples in the consumer-electronics industry in which SSOs successfully managed to coordinate include USB and Bluetooth. Those that were (partially) determined through a standards war include VHS and Blu-Ray. As we will see, our theory suggests that for a rich-enough contracting space, there is some initial coordination, even if a standards war may break out eventually, which indeed can be observed in the Blu-ray case.

standard.

Informational punishment can be carried out (i) through the SSO itself or (ii) by each firm individually. We discuss several business strategies for informational punishment: product pre-announcements, information leakage, and the provision of beta versions. Finally, we address the role of the signal sender's commitment. We show that the sender has no incentives for opportunistic behavior.

The main motivation of this paper is to explain the formation of SSOs. However, our findings apply to any setting in which parties coordinate in the shadow of a market solution. Examples include environmental agreements, coordination among legislators, strikes, litigation, and R&D alliances.

**Results.** Our analysis shows that a third-party's announcement that it will send a signal about one firm's cost structure can persuade another firm to join the SSO. The announcement relaxes participation constraints and thereby increases the set of implementable SSOs.

Informational punishment works because a signal realization about firm $i$ has two effects. The first effect is direct and distributional. It changes the other firms' perception of firm $i$'s cost structure. The second effect is indirect and behavioral. A firm's continuation strategy is a function of its information set. Obtaining more information alters the firm's continuation strategy. Via equilibrium reasoning, we can see that the firm's change in behavior alters the behavior of its competitors.

Bayesian updating implies that the distribution of posteriors averages to the prior distribution. The same does not hold for expected payoffs. The reason is that firms expect to adjust their behavior after each realization. Their continuation payoffs depend on the adjusted strategy profile. Expected payoffs are nonlinear in the information structure and hence expected payoffs before the signal's realization are not equivalent to expected payoffs if there is no signal at all.

Informational punishment exploits the behavioral channel. It decreases firms' outside options and thereby relaxes participation constraints. Under informational punishment, firms commit to releasing some of their private information if another firm vetoes the SSO. Releasing information influences the action choices of all firms in the market—those participating and those vetoing. The threat of information release persuades firms to participate in the SSO.

Informational punishment has a set of additional attractive features. First, it separates the signaling effect of a veto from firms' participation decisions. Second, it has no direct effect on either the (expected) outcome of the SSO or the incentive constraints because informational punishment operates off the equilibrium path. That is, the threat of informational punishment relaxes parties' participation constraints. Third, informational punishment does not need to be executed on the equilibrium path. In sum, informational punishment enlarges the set of implementable SSOs. Yet it does not rely on a third-part ability to enforce actions or on noncredible threats.

**Related Literature.** In line with Simcoe (2012), we assume that standard setting is a process in which industry consensus overcomes default market forces. While his focus is on bargaining under complete information, we use incomplete information as the predominant friction. Ganglmair and Tarantino (2014) also use an incomplete-information framework to model bargaining in R&D settings. While they study cases in which private information threatens to reverse an agreement, we study cases in which private information threatens the initial agreement. In a similar vein, our study complements Spulber (2018), who addresses the voting procedure inside organizations and how that interacts with the underlying market structure. Our model addresses an earlier stage. We are interested in whether firms decide to join an agreement and how they can convince others that coordination is better than the market.

In line with Farrell and Saloner (1985), we view a standards war as a contest between competing standards. Instead of engaging in a standards war, firms can coordinate on an SSO that governs their patent rights.[6]

We follow Farrell and Simcoe (2012) and assume that firms can choose from a set of SSOs to avoid the costly market mechanism. In line with them, we assume that firms hold private information about their own patents. However, unlike them, we are not primarily interested in whether the *optimal* standard arises. We are agnostic about the standard's quality and instead focus on the *standardization function* (Lerner and Tirole, 2015) of an SSO.

Dequiedt (2007) emphasizes the importance of nontrivial participation constraints in a model of collusion in auctions. Like us, he studies how participation constraints restrict the set of implementable outcomes. The crucial difference is that in our model, firms *cannot* commit to following recommendations of a third party if coordination fails. Instead, if a firm vetoes the SSO, the SSO becomes void and firms compete in the market. *All* firms select their individual best response in the market and he SSO itself influences these responses only indirectly through the information structure it implies *after* firms have observed who vetoed the SSO.

In our baseline model, we assume that the signaling device is offered by an impartial third party. That third party can commit to a certain device *before* eliciting firms' information. Under this assumption, concerns about informational opportunism such as those in Dequiedt and Martimort (2015) do not apply directly.

Informational punishment applies the tools of Bayesian persuasion (see the literature following Kamenica and Gentzkow, 2011)—in particular, convexification (Aumann and Maschler, 1995). Our problem differs in the collection of information. Information has to be elicited from the firms. That is, the signaling device has to satisfy incentive constraints. Moreover, in the persuasion literature, a designer actively persuades firms to take a certain action. Informational punishment works through a more subtle channel. A *signal*

[6] See also Besen and Farrell (1994) for an overview of the trade-offs involved. Baron, Li, and Nasirov (2018) revisit firms' motivation to join SSOs from an empirical perspective and emphasize the relevance of the issue.

persuades firms to participate in the proposed SSO by threatening to release information if the firms do not participate. Thus, on the equilibrium path, information is never provided. Instead, the threat alone convexifies outside options. As a consequence, the availability of a communication channel by itself fosters coordination, and persuasion occurs without the need for the signal to realize.

Gerardi and Myerson (2007) and Correia-da-Silva (2020) offer an alternative mechanism to induce participation. The main difference from our model is that in their models firms can verify neither a veto nor an acceptance decision. They propose a trembling device to relax participation constraints. The trembling device triggers a spurious veto *on the equilibrium path*. The existence of *on-path* vetoes eliminates the signaling value of an *off-path* veto, as firms cannot credibly signal that they caused the observed failure to coordinate. In our setup, trembling devices are ineffective since it is publicly observable which firm vetoed the mechanism. Instead, we propose informational punishment to get firms to participate. Unlike trembling devices, informational punishment has no influence on the SSO itself.

The fact that full participation need not be optimal even in rich mechanism spaces is documented in Celik and Peters (2011). In an extension, we show that if the mechanism space is rich enough, an SSO exists that is optimal *and* ensures full participation.

Our research also connects to our own work on information spillovers in mechanism design (Balzer and Schneider, 2019, 2021). In Balzer and Schneider (2019), we derive a general framework to design mechanisms with information spillovers in arbitration problems. There the choice of the mechanism affects the information structure and action choices *after* the mechanism is used. In this paper, by contrast, we are interested in how information revelation affects decisions *before* an exogenously given SSO arises. Balzer and Schneider (2019) ignore this consideration by assuming a fixed outside option for each type.

Balzer and Schneider (2021) address alternative dispute resolution in legal disputes. There, too, we consider a mechanism with a game as an outside option—namely, litigation. However, the litigation model in Balzer and Schneider (2021) implies that utility functions are convex in the information structure. Convexity makes informational punishment superfluous in that setting: initial participation in the mechanism is optimal even absent informational punishment. Information is relevant only *after* the mechanism. Indeed, informational punishment has no function in Balzer and Schneider (2019, 2021).[7]

[7]In addition to our own work, see Zheng (2019), who also leaves no room for informational punishment. All these papers model the outside option as an all-pay auction (Szech, 2011; Siegel, 2014). Moreover, the literature on information sharing in Cournot oligopolies (see, for example, Fried, 1984; Li, 1985; Okuno-Fujiwara, Postlewaite, and Suzumura, 1990) finds that it is beneficial even among competitors. The reason is precisely the convexity of profit functions in beliefs. In such industries, coordination on the optimal SSO is possible even absent informational punishment because participation constraints are not demanding.

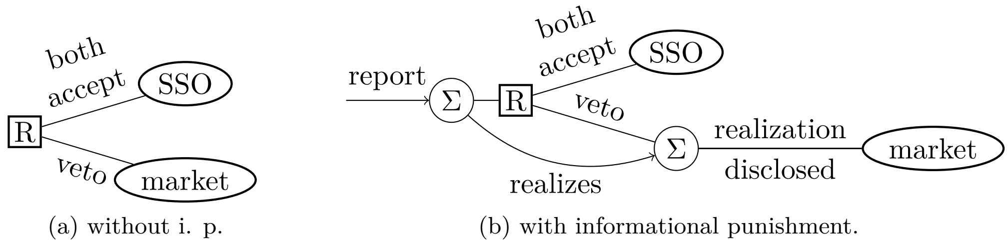


Figure 1: *(a) Standard setting without informational punishment and (b) standard setting including informational punishment.* In the ratification stage (R), firms decide whether to accept or veto the SSO. If they accept, the standard is set using the rules of the SSO; otherwise, the market determines the outcome. Informational punishment adds a signaling device, Σ, to which firms report *before* (R). The signal realization becomes public only *after* (R).

## 2 Model

**Players and Information.** There are two risk-neutral firms that aim to establish a novel standard. Firm $i$, with $i \in \{1, 2\}$, possesses binary private information $c_i \in \{1, k\}$ about its marginal cost to promote the standard.[8] We assume $k > 1$. The type of cost (high or low) is drawn from the known, firm-specific distribution $p_i^0 \in (0, 1)$, where $p_i$ is the ex ante probability that firm $i$ has type $c_i = 1$. Throughout we say a firm $i$ is (ex ante) *stronger* if $p_i$ is larger. We assume that $p_i^0 \geq p_{-i}^0$, that is, firm $i$ is the stronger of the two firms. Normalizing one of the types to 1 is without loss because only the ratio between types matters.[9]

There are two—mutually exclusive—ways to determine the standard: through the market (a standards war) or through coordination (through an SSO).

**Standards War.** We model the standards war as an all-pay contest. Firms compete for the right to set the standard. Winning the standards war provides the winning firm with an expected payoff normalized to 1.

The standards war is a contest with minimum investment $r > 0$.[10] Each firm invests $e_i \in [0, \infty)$ to convince the market that its standard is superior. Investment is costly, and the marginal cost of increasing investment is type $c_i$. We consider the simplest form of such a contest, in which the firm with the highest investment wins the standards war, provided $\max\{e_1, e_2\} \geq r$. Ties are broken at random. If both firms invest less than $r$, no standard is implemented and firms receive 0 profits. For clarity, we focus on the case in which $r$ is small: $r \in (0, 1/k)$. Extending the analysis to the remaining cases increases the

[8] Alternatively, we can think of these two firms as having a (not yet fully) developed format. Private information is then about the quality of the format—that is, the cost of fully developing it and bringing it to the market.

[9] Replacing $k$ with $c_h/c_l$ in all expressions provides an isomorphic model with types $\{c_l, c_h\}$.

[10] As we will see below, $r > 0$ implies that a positive investment is required to win the standards war even if the competitor is ready to concede immediately. That investment causes a simple concavity in the payoff function that facilitates informational punishment. We provide further discussion and an alternative modeling choice at the end of Section 4. See also Proposition 5 below.

number of case distinctions but does not alter either the intuition or the basic results.

**Standard-Setting Organization.** An SSO eliminates the cost of the standards war and thus generates surplus. We model the SSO as simply as possible. We assume that cooperation leads to a split of the surplus from the eventually established standard such that firm 1 receives share $x_1 \in [0, 1]$ and firm 2 receives the remaining surplus $x_2 = 1 - x_1$. In addition, we assume that cooperation makes the minimum investment $r$ redundant, ensuring that coordination on an SSO is the only efficient outcome from the industry's perspective.

**Informational Punishment.** Informational punishment consists of a signaling device, $\Sigma_i : \{1, k\} \to \Delta\{l, h\}$, for each firm. The signaling device takes type reports as inputs and maps them to a distribution of the signal realizations $\sigma_i \in \{l, h\}$.[11] It has the power to conceal any gathered information for some time.

**Solution Concept.** We are looking for perfect Bayesian equilibria (PBE). We assume Bayesian updating occurs whenever possible. Where it's not possible, we make the extreme assumption that any observed deviation is attributed to a low-cost firm. That is, if firm $i$ deviates and $-i$ observes that deviation, $-i$ holds the off-path belief $p_i = 1$.[12]

**Relationship with the DVD Case.** The model we set up above follows our interpretation of the evolution of the DVD standard. A standards war is a contest in which the two camps compete by investing in distributing their preferred standard. That investment may occur downstream through distribution of playback devices. It may also occur upstream through distribution of recording devices. Marginal costs of investment depend on knowledge a firm has obtained while developing its proposal for a standard.

Informational punishment is designed by a neutral third party that can provide an informative signal based on information provided by the firms. The TWG took that role in the DVD case. It made clear early on that its main goal was to prevent a standards war, but it was ex ante agnostic about which side should prevail. It scheduled an announcement to be made in the event that a standards war broke out. The threat of releasing information was sufficient to induce the firms to establish the DVD Consortium, and the TWG had no need to make the announcement.

After our analysis, we provide (in Section 4) alternative interpretations and other business strategies that could play the role of informational punishment.

[11] Note that in this two-firm version, correlation between $\Sigma_i$ and $\Sigma_{-i}$ does not matter. Indeed, firm $i$ can avoid reporting its type by refusing to participate in the SSO.

[12] The no-signaling-what-you-don't-know condition (Fudenberg and Tirole, 1988) of PBE is important for our analysis: firm $i$ cannot influence its *own* belief about the nondeviator (or alter common knowledge about it) by choosing to deviate. The assumption that the deviation of firm $i$ triggers an extreme off-path belief on the part of firm $-i$ *about* firm $i$, in contrast, is innocuous. No other (symmetric) off-path belief makes coordination on an SSO more likely. Issues with PBE arising in general sequential games (see, for example, Sugaya and Wolitzky, 2018) do not occur in our setting.

# 3 Analysis

We show that informational punishment increases the set of parameter values $\{r, k, p_1^0, p_2^0\}$ such that coordination on an SSO can be guaranteed. We proceed in two steps. First, we analyze a version of the model absent informational punishment. After that, we introduce informational punishment and compare the results. We say a standards war is *inevitable* whenever it is impossible to propose an $x_i$ that all types and firms will accept with probability 1.

## 3.1 Without Informational Punishment

Here we consider the coordination problem when informational punishment is not available. The timing is as follows (see also Figure 1, (a)):

1. Each firm privately learns its type realization, and the SSO announces the surplus shares $(x_1, x_2)$.
2. Both firms simultaneously decide whether to accept or veto the proposal $(x_1, x_2)$.

3a. If no firm vetoes the SSO proposal, it is implemented and firms receive $x_i$.

3b. Otherwise, all veto decisions become public, and firms engage in a standards war.

We solve the game using backward induction. We start by analyzing the standards war.

**Standards War.** The standards war is a continuation game, and the information structure thus depends on the history of play.

To decide what to invest in the standards war, firms use the public information structure and their private information about their cost type $c_i$. The (mixed) strategy of firm $i$ is a distribution of investments as a function of its cost. We denote it by the cumulative distribution $F_i^{c_i}(e_i)$. The *unconditional* distribution $F_i(e_i) = p_i F_i^1(e_i) + (1-p_i)F_i^k(e_i)$ describes $-i$'s *expectations* about $i$'s investment. Firm $-i$ wins the standards war if it invests more than $i$ does. To best respond to $i$'s strategy, $-i$ solves the following problem:[13]

$$\max_{e \geq 0} \begin{cases} 0 & \text{if } e < r \\ F_i(e) - c_{-i}e & \text{if } e \geq r \end{cases}$$

A key ingredient of the model is two-sided private information. Because there is private information *on both sides*, standards wars can be inevitable even if—as in our case—every party has full commitment power upon agreeing to join the SSO and there always is an SSO that is a strict Pareto improvement. The reason for failure is the mutual (and rational) optimistic belief that one's own cost is likely lower than that of the competitor.

[13] We implicitly conjecture an atomless equilibrium distribution $F_i$ in the description to abstract from ties. It turns out that indeed $F_i$ has no atoms for any $e_i > r$ in any equilibrium and that abstracting from ties is without loss (see also Siegel, 2014).

How much each firm invests in the standards war depends on (i) its own type, (ii) its belief about its competitor's type, and (iii) the equilibrium strategy of the competitor, which depends on the competitor's belief. A firm's strategy is monotone in its type. Moreover, if a low-cost (high-cost) firm $-i$ expects to face a stronger competitor $i$, it invests more (less). That, in turn, implies more (lower) investment by the low-cost competitor $i$, and so on.

When firms decide whether to start a standards war by exercising a veto, they foresee the (equilibrium) behavior in the standards war. Thus they expect equilibrium behavior in the continuation game.[14] In general, deriving the payoffs in contest games with two-sided private information is notoriously cumbersome.

Yet our main exercise is to characterize when it is possible to coordinate on an SSO. It turns out that for that purpose, it is sufficient to consider continuation games in which only one firm, firm $i$, vetoes the SSO proposal out of equilibrium. In that case, the belief about firm $i$ is $p_i = 1$ by assumption, whatever the firm's true type. Thus, in what follows, we restrict our attention to information structures of the type $I^i := (p_i, p_{-i}) = (1, p_{-i})$.

Restricting the analysis to such a setting implies asymmetric information is only one-sided. That setting is simpler to analyse. However, a special feature of our noise-free setting (compared to other forms of contests) is that the payoff functions are (piecewise) linear in a player's belief about the other player, and thus a full characterization is possible. We provide the characterization in Appendix B.2.

It is instructive to discuss the strategic reasoning of each type of firm. We begin with the nonvetoing firm $-i$.

**Firm $-i$ of high-cost type.** Firm $-i$ believes its competitor has low cost with probability 1. Facing a strong competitor implies either that $-i$ stays out of the contest altogether and immediately concedes or that it invests (in a neighborhood of) the minimum amount $r$. The latter possibility may be optimal because firm $i$ has an incentive to only invest such a moderate amount itself if firm $-i$ concedes with sufficiently high probability.

**Firm $-i$ of low-cost type.** Like its high-cost counterpart, the low-cost type of firm $-i$ believes that firm $i$ has low cost with probability 1. Thus, whenever firm $i$ moderately competes with firm $-i$'s high-cost type by investing (in a neighborhood of) $r$, low-cost type $-i$ has an incentive to invest beyond that to beat firm $i$ with certainty. In turn, the highest investment that firm $-i$ is willing to make has to match the highest investment that firm $i$ is willing to make: any higher investment implies that firm $-i$ is leaving money on the table.

**Firm $i$ of low-cost type.** The behavior of the low-cost type of firm $i$ depends on its belief about how likely it is that firm $-i$ has high cost. If firm $-i$ is seen as likely

[14] Note that even if entering the standards war is an off-path node, players correctly understand that this triggers an off-path information structure.

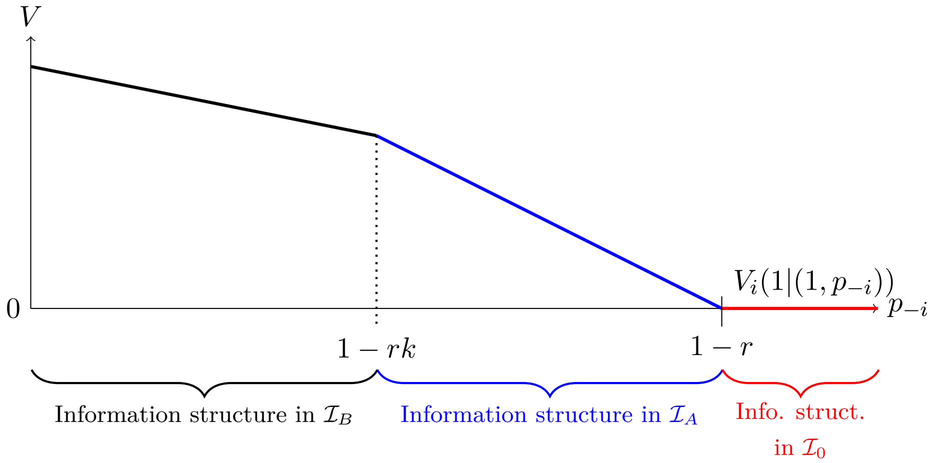


Figure 2: *Expected payoffs from the standards war.* Low-cost firm $i$'s payoff $V_i(1|(1, p_{-i}))$, as a function of $p_{-i}$.

to have high cost, the low-cost firm has a stronger incentive to only make a moderate investment. Firm $i$ expects to win the standards war against a high-cost firm $-i$ with such moderate investment. On the other hand, if firm $-i$ is seen as likely to have low cost, competition is fierce and firm $i$ is likely to invest more.

**Firm $i$ of high-cost type.** Finally, we have to consider the high-cost type of firm $i$ that its competitor mistakenly considers to be a low-cost firm with probability 1. As its competitor does not expect to face that type with positive probability, $i$'s behavior has no impact on equilibrium strategies. Depending on how fierce competition in the contest is, it either invests a moderate amount to win against high-cost firm $-i$ or it concedes and stays out of the contest.

Calculating the equilibrium implies the following payoffs in the continuation game.

**Lemma 1.** *Consider a standards war under the information structure $I^i := (1, p_{-i})$. The expected payoff of player $i$ of type $c_i$, $V_i(c_i|(1, p_{-i}))$, is:*

$$V_i(1|(1,p_{-i})) = V_{-i}(1|(1,p_{-i})) = \begin{cases} 0 & \text{if } p_{-i} \geq 1-r \\ 1-p_{-i}-r & \text{if } 1-r > p_{-i} \geq 1-rk \\ (1-p_{-i})\frac{k-1}{k} & \text{if } 1-rk > p_{-i} \end{cases},$$

$$V_i(k|(1,p_{-i})) = \begin{cases} 0 & \text{if } p_{-i} \geq 1-rk \\ (1-kr-p_{-i})\frac{k-1}{k} & \text{if } 1-rk > p_{-i} \end{cases},$$

$$V_{-i}(k|(1,p_{-i})) = 0.$$

If both firms are likely to have low cost, such that $p_{-i} > 1-r$, competition is fierce and rents are fully dissipated. We refer to this regime as $\mathcal{I}_0$. If firm $-i$ has an intermediate likelihood of having low cost, such that $p_{-i} \in [1-rk, 1-r]$, the low-cost-type of firm $i$

optimally reduces its investment to win only against high-cost firm $-i$ but with certainty. In this case, it invests only the minimum $r$. Thus, $i$'s payoffs are $1 - p_{-i} - r$: competition is less fierce; low-cost types have positive expected payoffs.[15] We refer to this regime as $\mathcal{I}_A$. If firm $-i$ is likely to have low cost, such that $1 - rk > p_{-i}$, firm $i$'s likelihood of offering only the minimum investment is so large that the high-cost firm $-i$ has an incentive to invest. Also in this case it is optimal for the low-cost firm $i$ to invest the amount that guarantees (only) a win against firm $-i$'s high-cost type. The necessary investment level for such a win is $(1 - p_{-i})/k$. Thus the payoff of firm $i$ is $(1 - p_{-i})(1 - 1/k)$. We refer to this regime as $\mathcal{I}_B$.

Expected payoffs are linearly decreasing in $p_{-i}$ within each region. Stronger competitors imply fiercer competition; and because the contest is frictionless, the marginal effect of an increase in a low type's likelihood is constant. However, changes in behavior imply a change in the slope of the payoffs when moving from one region to another. Figure 2 illustrates these breaks. If $p_{-i}$ is high, such that $p_{-i} > 1 - r$, the marginal payoff from an increase in $p_{-i}$ is 0. Rents are fully dissipated. For lower levels of $p_{-i}$, firm $i$'s payoff decreases in its competitor's expected strength. If $p_{-i}$ is low, such that $p_{-i} < 1 - rk$, competition becomes fiercer as $p_{-i}$ increases because low-cost-type firm $-i$ increases its investment. Yet the high-cost type of firm $-i$ concedes, giving an easy win to firm $i$. Once $p_{-i}$ crosses the threshold $1 - rk$, however, the high-cost type of firm $-i$ enters the competition and increases its (expected) investment as $p_{-i}$ increases. The decline in firm $i$'s payoff accelerates.

**Accepting a Proposal.** We now turn to the decision of whether to veto a given SSO proposal $x_i$. We continue to focus on the case in which the veto of firm $i$ is pivotal —that is, the case in which firm $-i$ is expected to accept the proposal. If firm $i$ accepts the proposal, it receives the (continuation) payoff $x_i$ and the game ends. In contrast, if firm $i$ vetoes the proposal, the standards war is triggered and Lemma 1 provides firms' continuation payoffs.

Suppose firm $i$ vetoes the proposal. Firm $-i$ concludes that firm $i$ is a low-cost type given our assumption on off-path beliefs. Firm $i$ is aware of firm $-i$'s updating. However, it cannot learn anything from its own veto and so it keeps the prior $p^0_{-i}$ about firm $-i$. Firm $i$'s outside option to accept the proposal is thus $v_i(c_i; p^0_{-i}) := V_i(c_i|(1, p^0_{-i}))$.

We begin with a simple yet important lemma that describes the high-level relationship between the (non-)occurrence of a standards war and the parties' outside options.

**Lemma 2.** *A standards war is inevitable if and only if* $v_1(1; p^0_2) + v_2(1; p^0_1) > 1$.

*Proof.* The reasoning is intuitive. Low-cost types can always mimic high-cost types, and thus $v_i(1; p_{-i}) \geq v_i(k; p_{-i})$. The proposal, $x_i$, is implementable if both players accept it. An acceptable proposal exists if and only if the low-cost types' continuation values add up to less than one. □

[15] Note that the equilibrium is in mixed strategies. The investment described above is therefore only one of the optimal investments of low-cost firm $i$. Since the firm is indifferent between all optimal investment levels, it is sufficient (and instructive) to focus on the choice outlined here.

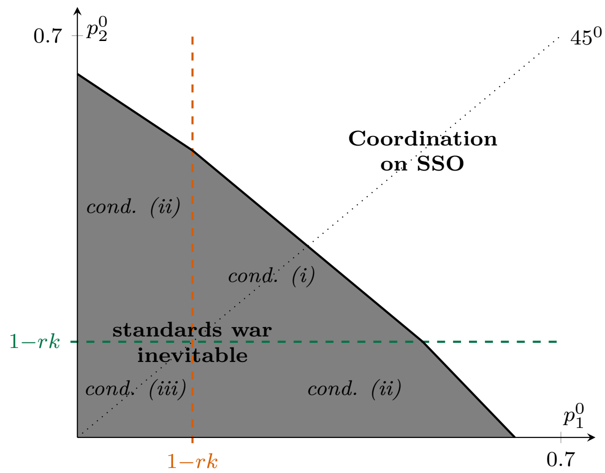


Figure 3: *Results without informational punishment.* The shaded area depicts the area in which a standards war is inevitable. Which condition applies is determined by the thick dashed lines. In the left bottom corner, $p^0_{-i} \leq p^0_i < 1-rk$ and condition (iii) applies. In the bottom right and top left, condition (ii) applies. In the top right, condition (i) applies.[a] The thick solid line depicts the frontier. The thin dotted line is the 45-degree line of symmetric distributions. In this example, $r = 1/6$ and $k = 5$.

[a] In this example, the left bottom area is entirely shaded, i.e., the second inequality in condition (iii) implies the first.

Applying Lemma 2 to our setting determines the parameter specifications for which a standards war is inevitable. Note that both firm $i$ and firm $-i$ can veto a proposal. We thus have to take into account which of these vetoes triggers which type of standards war (in terms of information structures $I^i$). Recall our convention that $p^0_i \geq p^0_{-i}$. The next proposition determines the parameter regions for which a standards war is inevitable. Figure 3 provides the corresponding illustration.

**Proposition 1.** *A standards war is inevitable if and only if one of the following (mutually exclusive) conditions holds:*

*(i)* $1 - 2r > p^0_1 + p^0_2$ *and* $p^0_{-i} \geq 1 - rk$,

*(ii)* $1 - (r + p^0_i)\frac{k}{k-1} > p^0_{-i}$ *and* $p^0_i \geq 1 - rk \geq p^0_{-i}$, *or*

*(iii)* $\frac{k-2}{k-1} > p^0_1 + p^0_2$ *and* $1 - rk > p^0_i$

The intuition behind Proposition 1 is as follows. If the likelihood that the competitor has low cost is sufficiently small, a low-cost firm expects little competition. Thus, it joins an SSO only if it will receive a favorable outcome. If both firms simultaneously expect to face a weak competitor, the sum of expected payoffs from a veto is larger than 1, ensuring at least one firm will veto the proposal.

A corollary to Proposition 1 is that when high and low costs are close to each other, such that $k < 2$, coordination is always feasible. The intuition is that failure to coordinate originates in the optimism of two low-cost types. Both believe that with high probability they can win the standards war with a low investment. When differences in cost are small, that statement does not hold even if the competitor is certainly a high-cost type. Marginal cost of $k < 2$ is not high enough to reduce the high-cost type's investment sufficiently.

### 3.2 With Informational Punishment

We now introduce informational punishment to the above model. The timing is as follows (see also Figure 1 panel (b)):

1. Each firm privately learns its type realization, the SSO announces the shares $(x_1, x_2)$, and the signaling devices $\Sigma_i$ are publicly announced.
2. Each firm reports to its $\Sigma_i$.
3. Firms simultaneously decide whether to accept or veto the proposal $(x_1, x_2)$.

4a. If neither firm vetoes the proposal, it is implemented and firm $i$ receives $x_i$.

4b. Otherwise, all veto decisions and realization $\sigma_i$ are publicly announced. Firms fight a standards war.[16]

Unlike in Section 3.1, firms now have the option to report to a given signaling device, $\Sigma_i$. For now, we assume that $\Sigma_i$ is known and committed. That is, the signaling device takes a firm's report as an input and maps it to an outcome, $\sigma_i$, according to $\Sigma_i$. Then it truthfully reveals that outcome in the event of a veto. In what follows, we characterize the triple $(\Sigma_1, \Sigma_2, x_1)$ that maximizes the likelihood that an SSO will be established.

We refer to the realization $\sigma_i = l$ $(\sigma_h = h)$ as the *low* (*high*) signal. Without loss, we use the convention that the low signal shifts the prior towards the low-cost type and the high signal shifts the prior towards the high-cost type. We characterize situations in which firms expect to coordinate on an SSO. Our discussion focuses on the case in which firm $i$ contemplates vetoing the SSO proposal.

**The Standards War.** We conjecture that firms report truthfully to $\Sigma_i$ on the equilibrium path, and we verify our conjecture later. A veto by firm $i$ leads to an off-path belief $p_1 = 1$. Thus, the signal realization about firm $i$, $\sigma_i$, provides no additional information.[17]

Suppose the signal about firm $-i$ is realized as $\sigma_{-i}$. It carries information about firm 2 (the nondeviator). Firm 1 (the deviator) uses that information to form posterior belief $p_{-i}(\sigma_{-i})$. The information structure is $I = (1, p_{-i}(\sigma_{-i}))$. The continuation payoffs follow from Lemma 1.

**Consistent Signals.** We now turn to the properties of the signaling device. Whatever signal is realized, firm $i$ forms a posterior. The posteriors are consistent with the priors. Consistency is a direct consequence of the firm's updating process. Firm 1 uses its knowledge about the mapping $\Sigma_{-i}$, the prior $p^0_{-i}$, and the realization $\sigma_{-i}$ and updates its belief about its competitor to a posterior $p_{-i}$ via Bayes' rule.

Let $\rho_i(\sigma_i)$ be the ex ante probability that signal $\sigma_i$ realizes. Consistency with the prior

[16] In principle, $\Sigma_i$ can also release a signal after firms have accepted the SSO. That realization is without any effect because firms are already committed to the SSO at that point.

[17] Note that since any firm can report any cost to the signal $\Sigma$, even the revelation that firm $i$ has reported high cost does not influence firm $-i$'s off-path belief. It simply assumes that firm $i$ had misreported to $\Sigma$ and is a low-cost type with probability 1.

implies the following:

$$\rho_{-i}(\sigma_{-i} = l)p_{-i}(\sigma_{-i} = l) + \rho_{-i}(\sigma_{-i} = h)p_{-i}(\sigma_{-i} = h) = p^0_{-i} \tag{1}$$

The ex ante likelihood that $\sigma_{-i} = l$ realizes is:

$$\rho_{-i}(\sigma_{-i} = l) = p^0_{-i}\rho_{-i}(\sigma_{-i}|c_{-i} = 1) + (1 - p^0_{-i})\rho_{-i}(\sigma_{-i}|c_{-i} = k) \tag{2}$$

Here, $\rho_i(\sigma_i|c_i)$ is the probability that signal $\sigma_i$ realizes conditional on the report $c_i$.

**The Optimal Signaling Device.** We now state the properties of the optimal signaling device, $\Sigma^*$. Then we highlight how to find it.

**Lemma 3.** *The signaling device that minimizes the probability of a standards war, $\Sigma_i^*$, has the following properties: the high signal is fully revealing (that is, $p_{-i}(\sigma_i = h) = 0$), whereas the low signal induces interior belief $p_{-i}(\sigma_i = l) = 1 - r$.*

We now discuss the construction of $\Sigma_i^*$. The corresponding formal arguments are in the proof of Lemma 3. Fix a signaling device about firm $-i$, $\Sigma_{-i}$. Its properties are commonly known, and so is the distribution of posterior beliefs. For each realized posterior, Lemma 1 states the resulting payoff from the standards war. Averaging over posteriors leads to a continuation payoff for a vetoing low-cost firm $i$ of $v_i(1; \Sigma_{-i}) := \rho_{-i}(\sigma_{-i}{=}l)v_i(1; p_{-i}(l)) + \rho_{-i}(\sigma_{-i}{=}h)v_i(1; p_{-i}(h))$.

Why does $\Sigma_i^*$ help to establish coordination? The standards war is a strategic game. The additional information firm $i$ receives about firm $-i$'s cost type, $\sigma_{-i}$, changes its equilibrium strategy. In turn, firm $-i$ changes its best response. In particular, whenever the low signal is sent, firm $i$ expects to face the low-cost type with high probability. It responds by aggressively investing in the standards war, triggering aggressive investments by firm $-i$. Rents are fully dissipated. Firm $i$ is worse off than under the prior. However, if the high signal is realized, firm $i$ is better off than under the prior. Its competitor is known with certainty to be a high-cost type. Importantly, both firms have common knowledge about the belief formation. As a consequence, the high-cost type reduces its investment to at most $1/k$ and the low-cost type of firm $i$ obtains a payoff of $1 - 1/k$. Because payoffs are nonlinear in information, the loss firm $i$ expects from signal $\sigma_{-i} = l$ outweighs the gain it expects from signal $\sigma_{-i} = h$. That is, the continuation payoff $v_i$ is concave in $p_{-i}$ in the relevant region. Concavity implies that, given two information structures, the expectation over continuation payoffs is less than the continuation payoff of the expected information structure. Providing $\Sigma_{-i}$ thu reduces the continuation payoff $v_i$.

Graphically, we obtain the optimal signal structure directly from Figure 4. Three observations lead to the result: (i) any posterior $p_{-i}(\sigma_{-i})$ corresponds to the posterior value of vetoing that is on the graph of $V_i(1|p_{-i}(\sigma_{-i}))$, (ii) any signal structure is a

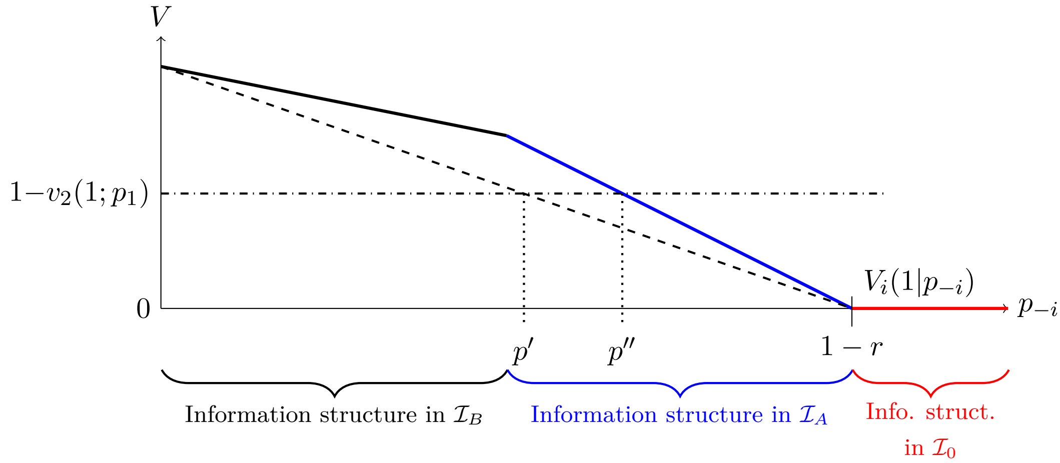


Figure 4: The value of vetoing for firm 1 given firm 2 assigns a probability $p_1$ to firm 1 having cost 1. The dashed line denotes the function's convex envelope. The dot-dashed depicts the residual resources after paying the minimum share to firm 2. For $k = 5$, $p_1 = 1/3$ and $r = 1/6$, it follows that $p' = 7/24$ and $p'' = 1/3$.

mean-preserving spread around the prior, $p^0_{-i}$, and (iii) the signal structure implies an expected value of vetoing—$v_i(1; p_{-i}(\sigma_{-i}))$—that is the convex combination of the two posterior values, with $\rho_{-i}(l)$ as the weight. Combining these three observations immediately leads to the result. Geometrically, $v_i(1; \Sigma_{-i})$ has to be on the line connecting the two postrealization payoffs $v_i(1; p_{-i}(l))$ and $v_i(1; p_{-i}(h))$. Moreover, $v_i(1; \Sigma_{-i})$ is the value of that line evaluated at the prior $p^0_{-i}$. The dashed line in Figure 4 represents that line under the optimal signal.

Why is $\Sigma^*_i$ optimal? The graphical analysis delivers the intuition. We want to minimize $v_i(1; \Sigma_{-i})$ over $\Sigma_{-i}$. The smallest $v_i$ the signal can induce is the largest convex function weakly below $v_i(1; p_{-i})$. The dotted line in Figure 4 provides that function for information structures $\mathcal{I}_A$ and $\mathcal{I}_B$. The optimal function picks the two extreme points in that region. One is $p_{-i} = 0$, and the other is $p_{-i} = \min\{1 - r, p_i\}$. Note that $p_{-i} = 1 - r$ because the veto belief $p_i = 1$.

Finally, we have to verify that truthfully reporting to the signaling device is incentive compatible. Each firm that plans to cooperate considers the information it provides to the signaling device as irrelevant on the equilibrium path. In fact, each firm uses the signaling device to threaten its competitor with informational punishment rather than planning to carry out that punishment. Thus, truthful reporting is optimal. Next, consider a firm that plans to veto the proposal. It has an incentive to strategically report to the signaling device if the realization influences the other firm's action in the event of the market solution. Yet once a veto becomes public, the other firm becomes aware of a deviation and may (as part of its off-path belief) disregard any realized signal. Thus, the optimal signal is incentive compatible.[18]

[18] In the discussion below, we consider an extension to the model in which the signal is able to produce hard evidence, but the result (and the general logic) remains.

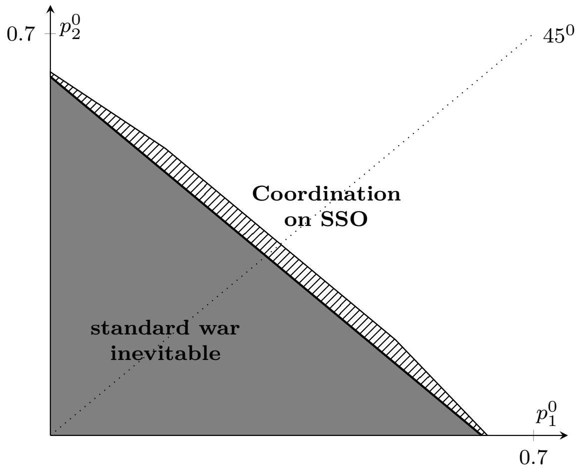


Figure 5: *Results with informational punishment.* The shaded area depicts the area in which a standards war is inevitable. The hatched area depicts the area in which coordination is only possible with informational punishment.

We now state the counterpart to Proposition 1 when allowing for informational punishment.

**Proposition 2.** *Suppose both firms have low cost. With informational punishment, a standards war is inevitable if and only if*

$$\frac{(1-r)(k-2)}{k-1} > p_1^0 + p_2^0.$$

*The parameter space in which the standards war is inevitable under informational punishment is strictly smaller than without informational punishment.*

Figure 5 graphically illustrates how informational punishment enlarges the parameter space in which coordination is possible. Observe that coordination is facilitated for any $p_{-i}^0$ in Figure 5 for which a standards war is inevitable for some $p_i^0$. That is, even as $p_{-i} \to 0$, informational punishment improves coordination.

Informational punishment shifts firms' beliefs about the state of the world. The shift has two effects. The first is *distributional*. The larger $p_i$ is, the more likely it is that firm $i$ has low cost. The second is *behavioral*. Fixing $-i$ to be a low-cost firm, the larger $p_i$ is, the fiercer the competition is. Thus, $-i$ invests more, and, in response, so does $i$. In equilibrium, investment increases overproportionally, making the standards war less attractive. Informational punishment exploits the second effect. Whether that exploitation is sufficient to guarantee coordination through an SSO depends on how close the parameters are to the region in which coordination is sustainable without informational punishment.

Informational punishment persuades firms to participate by threatening to release information that alters equilibrium play and thereby expected outcomes. However, as we see in Figure 5, informational punishment is not sufficient to guarantee participation in our simple model. If the set of potential SSO mechanisms is rich enough, coordination on an SSO is always possible but only if informational punishment is available. Proposition 5 in Section 5 provides the result.

# 4 Interpretation and Discussion

Informational punishment is a simple yet powerful signaling device. It requires the following features only. The device can commit to (i) concealing information for some time and (ii) releasing that information in a garbled way after the concealment time has passed. In this section, we discuss implications and interpretations of our findings.

## 4.1 When Is Informational Punishment Useful?

In the following, we fix an SSO and the associated expected outcome $x_i(c_i)$ awarded to each participating firm $i$ with cost $c_i$. We are interested in the case in which a specific firm of cost type $c_i$ rejects the SSO proposal absent informational punishment. The question we want to answer is: can we find an informational-punishment mechanism that, all else equal, will persuade $i$ to participate?

To proceed, we recall four objects. First, $p_{-i}$ is the belief that firm $i$ holds about firm $-i$'s cost distribution. Second, $p^0_{-i}$ is the ex ante prior that firm $i$ holds at the beginning of the game about that cost distribution. Third, $p^v_i$ is the belief that firm $-i$ holds about firm $i$ conditional on firm $i$ vetoing the proposal. Finally, $V_i(c_i|(p^v_i, p_{-i})$ is the value of vetoing to firm $i$ with cost $c_i$—that is, the expected continuation payoff from rejecting the proposal.

Our next result, Proposition 3, states that informational punishment is necessary to persuade cost type $c_i$ to participate in the SSO if $x_i(c_i) < V_i(c_i|(p^v_i, p_{-i}))$. Moreover, we show that, all else equal, informational punishment is sufficient if $x_i(c_i) \geq vex_{p_{-i}}(V(c_i|(p^0_i, p^0_{-i})))$, where the latter is the convex envelope of $V(\cdot)$ with respect to $p_{-i}$.

**Definition 1** (Convex Envelope)**.** The convex envelope w.r.t. to $y$, $vex_y(f(t,y))$, of a function $f$ is the largest function convex in $y$ that is (pointwise) smaller than $f$:

$$vex_y(f(t;y)) := \sup\{g_t(y) : g_t(y) \leq f(t;y) \text{ and } g \text{ convex}\}.$$

**Proposition 3.** *To persuade cost type $c_i$ to participate in an SSO with expected payoff $x_i(c_i) < V_i(c_i|(p^0_i, p^0_{-i}))$, informational punishment is necessary. If, in addition, $x_i(c_i) \geq vex_{p_{-i}}(V_i(c_i|(p^0_i, p^0_{-i})))$, then informational punishment is also sufficient to persuade $c_i$.*

## 4.2 Alternative Interpretations

We now discuss a set of real-world business strategies that could serve as (de)centralized informational-punishment mechanisms as an alternative interpretation of our model.

### Informational Punishment through the SSO

An alternative way to interpret our model is to assume that the SSO itself includes informational punishment. Provided that a neutral third party governs the SSO, such an interpretation is without loss. That is, if the TWG had simultaneously set up the SSO *and* the informational-punishment mechanism, the results would be identical. As in the above interpretation, commitment power seems crucial at first sight. However, we show in Section 5 below that allowing for opportunistic behavior does not alter the results.

### Decentralized Informational Punishment

We now turn to the scope of informational punishment provided by the firms themselves. We address several business strategies common in the innovation industry and how they can be interpreted as means of informational punishment.[19]

**Vaporware.** Vaporware describes products that are pre-announced but then never produced. Announcing products before production has even begun is a common business strategy in standards wars (Shapiro and Varian, 1998, ch. 9). The use of these product announcements to influence the strategic behavior of rival firms is well documented. Here we argue that product announcements can serve as informational punishment.[20]

Consider our baseline model without informational punishment. In addition, assume that, prior to deciding whether to join the SSO, the firm announces a product that is not yet fully developed. The likelihood of the product's realization is correlated with the underlying cost function. If an SSO decides on the standard and the firms coordinate, the announcement has no strategic value. However, if the SSO is rejected, the market observes whether the product is actually developed or has become vaporware. Firms update their beliefs and choose their strategies in the market.

In the product-announcement stage, the firm can control what type of product it announces. The announcement itself is cheap in the sense that the firm is free to announce a product it has no intention to work on. Depending on the announcement, the outcome (rollout or vaporware) may be interpreted differently. Thus, the announcement determines the precision of the signal.

The main difference between product announcements and the informational-punishment mechanism outlined above is that here firms choose the signal precision themselves and do not delegate it to a third party.

Now suppose the following announcement strategy is adopted. Both the high-cost firm and the low-cost firm announce a product that is straightforward for a low-cost firm to

[19] In some of the interpretations presented below, the signal produces verifiable evidence, while our baseline model assumes that reports to $\Sigma_i$ are nonverifiable. It turns out that in our model, there is no qualitative difference between the two since the incentive constraint to truthfully report to $\Sigma_i$ is nonbinding in equilibrium and a potential deviator has no incentive to fully reveal its costs if they are high.

[20] Among others, Dranove and Gandal (2003) provide evidence for the use of vaporware in standard setting. Bayus, Jain, and Rao (2001) analyze the presence of vaporware in innovative markets in general. Theoretical arguments are provided by Farrell and Saloner (1986) and Besen and Farrell (1994).

develop but whose development may fail if a firm has high cost. If a firm does not manage to launch the product, its high cost is revealed. Ability to launch the product, on the other hand, is not conclusive for demonstrating low cost. Correctly calibrating the difficulty for high-cost firms replicates the optimal signal constructed above.

Firms completely control the precision of the signal when making a product announcement. We now show that they have no incentive to deviate through adopting a different announcement strategy. We start with announcements that fully reveal the type. For a low-cost deviator, a proof of type is irrelevant, as the nondeviating firm expects the deviator to have low cost anyways. A high-cost deviator never profits from proving its high cost. All non-fully-revealing off-equilibrium product announcements are evaluated in light of the off-path belief $p_i = 1$. Any non-fully-revealing announcement strategy cannot alter that belief. Results are identical to the baseline model.

**Leaking Documents.** An important aspect of standards wars is taking advantage of the narrative of the standards war.[21] While informational releases by the firms might not have much of an impact, their evaluation by the business press may affect the narrative (see Bushee et al., 2010, for empirical work on the role of the press).

To influence press coverage, firms can strategically leak information to the press. If the information is evaluated positively, this may help the firm to take advantage of the narrative and provide a coordination device for undecided consumers. If the information is evaluated negatively, the opposite may be the case.

In addition, assume that (i) journalists fact-check the information and bundle it with their own investigation and (ii) the information is most valuable to journalists if the firms cannot coordinate on a standard. Then the press has an incentive to publish its evaluation of the information only after coordination on a standard fails.

Under these assumptions, information leakage works precisely like product pre-announcements. All firms leak similar information to the press. If the firm has low cost, no contradictory evidence can be found. If the firm has high cost instead, the press may or may not find evidence contradicting the leakage. The optimal signal is replicated. Much as in the vaporware discussion, firms have no incentive to leak different information to the press.

**Beta Versions.** Another strategy to influence the information in the market is to provide beta versions of the intended product range. Beta versions provide information about the expected quality of the final product and thereby influence the strategies of the rival firms. The main strategic difference from information leakage and product announcements is that beta versions might contain hard evidence about a firm's cost structure. Indeed, by analyzing a rival's beta version, a firm can partially verify that rival's technology.

[21] "It's not enough to have the best product; you have to convince consumers that you will win" Shapiro and Varian, 1998, ch. 9

The results are identical to those in our baseline model. All firms claim low cost in releasing their beta version. If the beta version contains severe bugs (the $h$-signal), the market updates negatively; otherwise, it updates positively (the $l$-signal). As in the previous two cases, the firm has no incentive to intentionally provide bugs to signal high cost.

### 4.3 Underlying Model Assumptions

The assumptions of two players and two cost types are purely technical and for expositional convenience. Increasing the type space to a (finite) number of costs complicates the algebra but does not alter the results nor the intuition behind. In the following, we discuss in greater detail our underlying economic assumptions. We assume that vetoes become public. Yet we only require that a firm *can* verify its veto. Indeed, vetoes have a signaling aspect. Often a veto signals confidence and provokes less aggressive actions by a rational competitor. In the DVD case, absence from the SSO meetings would credibly signal a firm's veto decision.

We model the standards war as a contest with some minimum investment. In a standards war, both firms invest in the distribution of their standard, and investment increases the chances of winning the war. The minimum investment is required if the standard is to (partially) replace some existing formats. In the DVD case, these formats were mainly CD and VHS. Earlier attempts to replace the CD and VHS formats—for example, by the LaserDisc or the MiniDisc—failed because the disruptors did not manage to invest a sufficient amount to reach critical market penetration.[22] Without the minimum investment, a frictionless standards war would not leave any scope for informational punishment, because expected payoffs would be linear in $p_{-i}$. However, introducing other frictions—for example, a noisy mapping from investment levels to wins—would also imply concavities in the payoffs and thus room for informational punishment. See Appendix C for an example.

In our model, informational punishment requires a trustworthy information gatekeeper. In particular, at the ratification stage, the signal structure is public but the signal realization is not. We have seen that this assumption is innocuous in many aspects of our stylized model. Yet in the DVD-standard process the TWG acted as a trustworthy information gatekeeper. Indeed, the TWG had published a list of nine vague desires they had on high-density disc. From the observer's point of view, these objectives did not send a signal directly. However, it seems likely that the two camps themselves may have had a good sense of the TWG's evaluation *procedure* and the implied uncertainty.

[22] See the textbook of Shapiro and Varian (1998) for more information and case studies on strategies in standards wars.

# 5 Extensions

In this part we provide three extensions of our model:

1. We introduce informational opportunism; that is, the designer of informational punishment behaves strategically too.
2. We allow for more sophisticated mechanisms than the take-it-or-leave-it offer $x_i$ in the baseline model.
3. We discuss the case of more than two firms.

## 5.1 Informational Opportunism

Here we assume the designer is a strategic player herself. She aims to prevent the standards war. However, she cannot commit ex ante to the signaling device $\Sigma$. Dequiedt and Martimort (2015) show that such informational opportunism can overturn the outcome derived under commitment.[23]

We construct a set of signaling devices, $\Sigma_i^{EPIC}$, that allows for informational opportunism. In particular, we assume that $\Sigma_i^{EPIC}$ is chosen after the veto is observed, and thus it is *ex post incentive compatible* for the designer. We show that the outcome is identical to that of our baseline model. Informational punishment is thus *immune* to informational opportunism. Under informational opportunism, the sequence is as follows:

1. Each firm privately learns its type realization, and the SSO announces the shares $(x_1, x_2)$.
2. Each firm reports $m_i$ to the designer.
3. Firms simultaneously decide whether to accept or veto the proposal, $(x_1, x_2)$.

4a. If no firm vetoes the proposal, it is implemented and firms receive $x_i$.

4b. Otherwise, $\Sigma_i^{EPIC}(m_i)$ is chosen and publicly announced together with the veto decision and the realization $\sigma_i^{epic}$. Firms engage in a standards war.

**Proposition 4.** *Informational punishment is immune to informational opportunism. That is, the optimal signaling devices, $\Sigma_i^{EPIC}$ and $\Sigma_i^*$, in the two scenarios coincide, such that $\Sigma_i^{EPIC} = \Sigma_i^*$.*

## 5.2 Sophisticated Mechanisms

Our model shows that informational punishment can help to induce parties to coordinate on a standard in certain environments. Yet, for any $p_2 < p'$ in Figure 4, no SSO of the kind $x_i$ exists even with informational punishment. Our model predicts a standards war without further negotiations in these cases.

In reality, we seldom observe such outcomes. Even if a standards war occurs eventually, we typically observe negotiations beforehand. For example, before the standards war

[23] The TWG's press releases (see Taylor (2001) for a discussion) arguably suggest that the TWG was indeed a strategic designer and therefore may have suffered from informational opportunism.

between HD-DVD and Blu-ray broke out, several rounds of negotiation had taken place. The reason our model does not predict such negotiation lies in our stylized view of SSOs. While in reality there are many ways firms can coordinate on a standard, we (artificially) restrict ourselves to a single take-it-or-leave-it offer.

How do the benefits of informational punishment generalize to richer SSOs? In a richer setting, informational punishment (i) guarantees participation in an SSO (even if the SSO cannot guarantee agreement on a standard) and (ii) increases the set of implementable SSOs. The reason is that informational punishment operates off the equilibrium path by punishing a firm not participating in an SSO but becomes irrelevant once all firms have accepted an SSO.[24]

We extend the definition of an SSO as follows. In its most abstract form, an SSO is a one-shot mechanism. A firm accepts that mechanism by reporting its type $\hat{c}_i \in \{1, k\}$. If both firms report their type, the report profile probabilistically determines which of the following two outcomes is realized: (i) they agree on a share $x_i$ (in which case a standards war is avoided), or (ii) they disagree, and a standards war breaks out. Formally, the definition is as follows.

**Definition 2.** The set of SSOs, $\mathcal{SSO}$, is the set of all mappings

$$SSO = (\gamma, x_1, x_2) : \{1, k\}^2 \to [0,1] \times [0,1] \times [0,1]$$

such that $x_1 + x_2 \leq 1$.

In the case of an agreement, which happens with probability $\gamma(\hat{c}_1, \hat{c}_2)$, a firm's payoff is equal to its attributed settlement share. In the case of a disagreement, which happens with the remaining probability, each firm uses its knowledge about its own type report together with its competitor's commonly known equilibrium reporting strategy to update its beliefs about the on the (on-path) information structure, $I = (p_1, p_2)$. A firm's (expected) payoff from the disagreement outcome is thus given by $V_i(c_i|\hat{c}_i, I)$.[25]

The set $\mathcal{SSO}$ describes all possible normal-form games that determine the standard when the outside option is the market solution. Observe that any SSO $\in \mathcal{SSO}$ with $\gamma = 1$ is the market solution itself. Thus in principle we can allow the SSO to replicate the market.

Thus, in equilibrium, a firm's expected payoff from joining the SSO is:

$$\begin{aligned} &p^0_{-i}[\gamma(c_i,1)x_i(c_i,1) + (1-\gamma(c_i,1))V_i(c_i|c_i,I)] \\ &+(1-p^0_{-i})[\gamma(c_i,k)x_i(c_i,k) + (1-\gamma(c_i,k))V_i(c_i|c_i,I)] \end{aligned}$$

[24] A richer way to model an SSO might be to allow for negotiations among many firms. The outcome of those negotiations is then either a common standard (with a distribution of royalties among firms) or a standards war. In such a setting, firms' participation constraints are not necessarily trivial: firms' behavior during those negotiations can reveal some of their private information. This revealed information, in turn, affects firms' behavior in the event that a standards war occurs and thus also affects their willingness to accept an agreement. In such a setting, informational punishment incentivizes firms to participate in these negotiations in the first place.

[25] $V_i(c_i|\hat{c}_i, I)$ depends explicitly on $\hat{c}_i$, as a firm might deviate from equilibrium.

$I$ depends on $\gamma$ via Bayes' rule. Importantly, given an informational-punishment device $\Sigma$, a firm's expected payoff from vetoing the SSO proposal is the same as in Section 3.

Deriving the optimal mechanism requires taking a stand on the designer's objective. It is, in general, complicated and beyond the scope of our paper. In Balzer and Schneider (2021), we construct a disagreement-minimizing mechanism for a version of our model with $r = 0$ in a different context. Here we focus on whether informational punishment helps in such an extended setting.

Celik and Peters (2011) show that there are cases in which the optimal mechanism involves on-path rejection by some players or cost types. The reason is that parties have an incentive to use rejections as a signal of their type, and thus the revelation principle fails. Here we show that if we augment the setting with informational punishment, the concerns of Celik and Peters (2011) become obsolete: an optimal full-participation mechanism always exists.

**Proposition 5.** *Suppose the set of mechanisms is $\mathcal{SSO}$. It is without loss of generality to focus on those SSOs that imply full participation when informational punishment is available.*

### 5.3 Many Firms

Standards in the computer industry or the cell phone industry are perhaps subject to more technological complexity than the standard for discs, which were (at first) only designed for video playback. However, even in the DVD case, several firms organized themselves into the two industry consortia. Despite the organization, each firm might still have its own agenda. Here we address two settings: (i) consortia formation prior to the development of a standard, and (ii) an SSO that has to coordinate among multiple firms.

Consider the stage in which firms start to think about whether to form a consortium.[26] At that stage, each firm takes into account the fact that the industry will eventually settle on one standard once the consortia are formed. Forming a consortium—an SSO that sponsors a particular standard rather than the alternatives available outside the SSO—is beneficial. It increases the surplus of the participating firms by allowing them to coordinate their strategies.

Once formed, a consortium competes with the remaining firms in a second stage. Yet a consortium still provides each participating firm with an expected surplus $x_i(c_i)$ that depends on its private information. That expected surplus has to be larger than a firm's value of vetoing $v_i(c_i; I)$, which may be the (expected) payoff from joining the *competing* standard. In particular, if key players are expected to not participate, $x_i(c_i)$ decreases and other firms may want to stay out of the consortium too, leading to the complete breakdown of the consortium. Informational punishment of firm $i$ can facilitate participation by firm

[26] In the introductory example, the consortia were the MMCD camp of Sony and Philips and the SD camp of Toshiba and Time Warner.

$j$ precisely as in Section 3. If it does, and if firm $i$ finds it beneficial to make firm $j$ participate, it has an incentive to carry out informational punishment.

A similar case applies to consortia that are formed to *develop* a standard.[27] Such consortia act as standard-developing organizations (SDOs). In that case, the ratification of an SDO's standard replaces our participation decision. The SDO decides on the standard and on the distribution of royalties of included patents, and the patent holders vote on whether to accept the proposal. If they vote to accept, the standard is implemented and patent holders obtain their payoff $x_i$. If anyone votes to reject, the standard is modified and does not include the proposed patent. Now the patent holder has to be sure to prevail on the market against alternative specifications. Its expected payoff is $v_i(c_i; I)$, which depends on the public belief about the power of the patent holder's technology compared to the alternatives. Informational punishment may help to discipline ratification.

A second aspect absent in the two-firm model arises if we design an SSO that all firms are supposed to join but in which an individual veto still allows for coordinated actions by the remaining firms. If firms can hand over authority to the SSO, such a scenario provides an additional punishment instrument to the SSO. If a firm that is supposed to participate deviates, the SSO instructs the complying firms to choose the market action that minimizes the deviator's payoff. Depending on the SSO's commitment power, the scope of such punishing-the-deviator strategies varies. If the SSO has full authority and commitment power, it can promise to punish a deviator even at the cost of the participating firms. If, however, the commitment power of the SSO is limited, the punishment is limited to making (interim) optimal choices.

Informational punishment is independent of the SSO's authority and commitment power. It punishes a potential deviator through information about the complying firms. It is not conditioned on the SSO itself or on the commitment options of the outside competitors. It requires only that firms can conceal some information and credibly commit to releasing information if participation turns out to be different from expected.

In any of the above scenarios, an industry consists of $n$ firms. Depending on the context, an SSO (or SDO) may only target $n' \leq n$ of them. A targeted firm's continuation payoff from accepting an SSO depends on the bargaining protocol or the voting procedure within the SSO and also on what happens after an SSO comes to a decision. In general, the firms' interaction within an SSO can be a complicated, dynamic process. For example, SSOs might not adopt standards by unanimous consent. That is, even though all $n'$ targeted firms initially agreed to join the SSO to establish a standard, only a subset of them might eventually agree on one.

Nevertheless, our model remains valid. Equilibrium behavior conditional on joining an SSO implies a mapping from firms' private information to (i) the $n'$ firms' joint payoffs

[27] Examples include the World Wide Web Consortium (W3C), the Internet Engineering Task Force (IETF), the Institute of Electrical and Electronics Engineers (IEEE), and the European Telecommunications Standards Institute (ETSI).

and (ii) a distribution of these payoffs among the $n'$ firms.[28] A firm only joins an SSO if its continuation payoff from that action, $x_i(c_i)$, is larger than the value from not joining the SSO—a payoff, $v_i(c_i; I)$, that depends on equilibrium reasoning and the implied information structure.

# 6 Conclusion

We consider an SSO seeking to determine a standard in an industry. Informational punishment can be a powerful tool to induce privately informed firms to cooperate to set a standard. That way, the likelihood of a standards war is severely reduced or even completely eliminated.

We model informational punishment as a trustworthy signaling device. The device elicits information from participating firms. It releases a noisy signal of this information if the firms fail to coordinate on an SSO proposal. We show that the threat of the signal's realization relaxes firms' participation constraints. Our model contributes to the discussion of whether it is always good to talk even if the outside option is lucrative. We show that talking to an impartial third party is sufficient to sustain some cooperation. The key feature is that the third party herself promises to talk if firms cannot coordinate.

Our findings allow for several interpretations of real-world phenomena. For example, they can explain strategic information leakage, risky product announcements that potentially turn into vaporware, and the release of beta versions. In all these business strategies, firms commit to releasing an informative signal in the future. That way, competing firms are persuaded to cooperate.

Methodologically, our approach allows for tractable solutions to a variety of applied problems beyond SSOs. Vetoes and Bayesian games as outside options are present in many areas of coordination among firms. They are relevant in the problem of political bargaining in the shadow of a popular vote and in financial markets when creditors decide whether to act jointly or independently in dealing with a borrower in distress.

Informational punishment increases the number of outcomes competitors can coordinate on. Thus, when evaluating the potential for cooperation among competitors, a regulator should carefully consider whether informational punishment is available to firms.

[28] This could be, for example, the continuation payoffs from teaming up, as in the formation of the MMCD and SD camps, where $n' = 2$.

# Appendix

## A Proofs

### A.1 Proof of Lemma 1

*Proof.* The proof is a direct application of Siegel (2014). We present the full proof (including all other cases) in Appendix B. $\square$

### A.2 Proof of Proposition 1

*Proof.* By Lemma 2 a standards war is inevitable if $v_1(1; p_2^0) + v_2(1; p_1^0) > 1$. Lemma 1 determines the relevant payoffs. The result follows from the respective calculations when using $p_i^0 \geq p_{-i}^0$. We discuss case 0 for completeness only.

**Case 0:** $p_i \geq 1 - r$**.** A veto by firm $-i$ implies a standards war under regime $\mathcal{I}_0$. It thus expects a payoff of 0 from vetoing. Promising the entire surplus to firm $i$ is incentive compatible and guarantees coordination

**Case 1: Assume** $p_i^0, p_{-i}^0 \in [1 - rk, 1 - r]$**.** A veto by any firm implies a standards war under regime $\mathcal{I}_A$ with associated payoffs $v_i(1; p_{-i}^0) = 1 - p_{-i}^0 - r$ and $v_{-i}(1; p_i^0) = 1 - p_i^0 - r$. The sum is larger 1 if $p_1^0 + p_2^0 < 1 - 2r$ which implies condition (i).

**Case 2: Assume** $p_i^0 \geq 1 - rk > p_{-i}^0$**.** A veto by firm $i$ implies a standards war under regime $\mathcal{I}_B$ while a veto by firm $i$ implies regime $\mathcal{I}_A$. The corresponding payoffs are $v_i(1; p_{-i}^0) = (1 - p_{-i}^0)\frac{k-1}{k}$ and $v_{-i}(1; p_i^0) = 1 - p_i^0 - r$. The sum is larger 1 if $p_{-i}^0 < 1 - (r + p_i^0)\frac{k}{k-1}$ which is condition (ii).

**Case 3: Assume** $1 - rk \geq p_i$**.** A veto by any firm implies a standards war under regime $\mathcal{I}_B$. The corresponding payoffs are $v_i(1; p_{-i}^0) = (1 - p_{-i}^0)\frac{k-1}{k}$ and $v_{-i}(1; p_i^0) = (1 - p_i^0)\frac{k-1}{k}$. The sum is larger 1 if $p_i^0 + p_{-i}^0 < \frac{k-2}{k-1}$ which implies condition (iii). $\square$

### A.3 Proof of Lemma 3

*Proof.* Note first that the standards war minimizing signaling device, $\Sigma_i^*$, minimizes the payoffs of the low-cost type of firm $i$.

Fix $V_i(p|(1, p_{-i}))$ which is concave on $p_{-i} \in [0, 1 - r]$.[29] The following lemma proves that concavity is sufficient for the desired signal properties.

[29] It is concave because there is at most a switch from regime $\mathcal{I}_B$ to regime $\mathcal{I}_A$ as $p_{-i}$ increases by Lemma 2. The payoff is piecewise linear decreasing with more negative slope in regime $\mathcal{I}_A$ compared to regime $\mathcal{I}_B$.

**Lemma 4.** *Suppose $f : [0,1] \mapsto \mathcal{R}$ is concave on $[a,b] \subset [0,1]$. Then, there exists an optimal signaling function putting mass on $a$ and $b$ only.*

*Proof.* For given $\bar{x} \in (a,b)$ we need to solve the following minimization problem:

$$\min_{x_n, \lambda^n \in [0,1]} \sum_n \lambda^n f(x_n),$$

subject to the constraints that $\sum_n \lambda^n x_n = \bar{x}$, $x_n \in [a,b]$, and $\lambda^n \geq 0$ such that $\sum_n \lambda^n = 1$.

Take any such $\{x_n\}_n$ with implied $\lambda^n$. The solution value of the minimization problem is

$$\sum_n \lambda^n f(x_n).$$

Now note that because $[a,b]$ is the convex hull generated by the points $a$ and $b$, for each $x_n$ there exists $\alpha^{x_n} \in [0,1]$ such that $x_n = \alpha^{x_n} a + (1-\alpha^{x_n})b$. Substituting into the solution value this becomes

$$\sum_n \lambda^n f(x_n) = \sum_n \lambda^n [f(\alpha^{x_n} a + (1-\alpha^{x_n})b)] \geq \sum_n [\lambda^n \alpha^{x_n} f(a) + \lambda^n (1-\alpha^{x_n}) f(b)],$$

where the last inequality follows from concavity of $f$.

Next, note that $\bar{\lambda} \equiv \sum_n \lambda^n \alpha^{x_n} \geq 0$ as $\alpha^{x_n}, \lambda^n \geq 0$. Moreover, $1 - \bar{\lambda} = 1 - \sum_n \lambda^n a^{x_n} = \sum_n \lambda^n (1-\alpha^{x_n}) \geq 0$, where we used that $\sum_n \lambda^n = 1$. Thus, $\bar{\lambda} \in [0,1]$. Finally, note that $\bar{\lambda} a + (1-\bar{\lambda}) b = \sum_n \lambda^n [\alpha^{x_n} a + (1-\alpha^{x_n}) b] = \sum_n \lambda^n x_n = \bar{x}$. Thus, choosing two signals $a$ and $b$ with weights $\bar{\lambda}$ is a feasible solution for the minimization problem.

□

□

## A.4 Proof of Proposition 2

*Proof.* Suppose firm $i$ rejects the mechanism. Then, $p_i = 1$. Moreover, the optimal signal implies that $p_{-i}(h) = 1$ and $p_{-i}(l) = 1 - r$. Thus, $\rho_{-i}(l) = p^0_{-i}/(1-r)$ and $v_i(1; \Sigma^*) = (1 - \rho_{-i}(l)) \frac{(k-1)}{k} = (1 - r - p^0_{-i})(k-1)/(k(1-r))$. Moreover, $\sum_i v_i(\Sigma^*, 1) > 1$ if and only if

$$(2(1-r) - p^0_1 - p^0_2) \frac{(k-1)}{k(1-r)} > 1 \Leftrightarrow \frac{(1-r)(k-2)}{k-1} > p^0_1 + p^0_2.$$

The condition derived necessarily includes then the (joint) condition derived in Proposition 1. The reason is that an uninformative signal device is always feasible replicating the situation without informational punishment. Since $\Sigma^*$ is chosen optimally, the claim trivially holds. However, the parameter space for which a standards war is inevitable is in fact *strictly* smaller under informational punishment, that is, under the optimal device $\Sigma^*$.

Comparing the condition from Proposition 2 with the three conditions from Proposition 1 implies directly that the condition in Proposition 2 is stricter than (i) and (iii) independent of $p_i^0, p_{-i}^0$. The condition from Proposition 2 is stricter than condition (ii) if $1-2r-p_i > 0$ which holds whenever condition (ii) applies because the LHS of condition (i) and (ii) respectively intersect at $p_1 = 1 - rk$ with condition (ii) having the more negative slope. Since both are linear, this implies that for $p_1 > 1 - rk$ condition (ii) is weaker than the condition from Proposition 2. That, in turn, implies that the condition from Proposition 2 is indeed stricter which proves the claim (see Figure 3 for an illustration). □

## A.5 Proof of Proposition 3

*Proof.* Suppose $x(c_i) \in \Big[vex_{p_{-i}}(V_i(c_i|(p_i^0, p_{-i}^0))), V_i(c_i|(p_i^0, p_{-i}^0))\Big)$.

Absent informational punishment type $c_i$ would reject the offer from the SSO.

We want to show that there is an informational punishment mechanism that persuades $c_i$ to participate. Firm $c_i$ participates if $x_i(c_i)$ is not smaller than the value of vetoing. Suppose the other firms can send a signal of arbitrary precision about their type distribution. Any such signal must be Bayes' plausible, that is, $\sum_{\sigma_{-i}\in\Sigma_{-i}} \rho_{-i}(\sigma_{-i})p_{-i}(\sigma_{-i}) = p_{-i}^0$. Using (the inverse of) standard concavification arguments, we know that $\mathbb{E}_{p_{-i}}[V_i(c_i|(p_i^v, p_{-i}(\sigma_{-i}))|\Sigma_{-i}] \geq vex_{p_{-i}}(V_i(c_i|(p_i^0, p_{-i}^0)))$.

If $x_i(c_i) \geq V_i(c_i|(p_i^0, p_{-i}^0))$, $c_i$ participates without any persuasion through informational punishment, if $x_i(c_i) < vex_{p_{-i}}(V_i(c_i|(p_i^0, p_{-i}^0)))$ informational punishment cannot persuade $c_i$ to participate. □

## A.6 Proof of Proposition 4

*Proof.* The proof is constructive.

It is useful to identify the designer by the message she received. We call it the designer's type. For now, assume firms told the truth to the designer. Therefore, a *high* (*low*) device knows the non-deviating firm has high (low) cost. We construct a pooling equilibrium in which each type announces the same $\Sigma_i^{EPIC}$ which is identical to $\Sigma_i^*$ from Lemma 3.

Consider first the *low* type. It is indifferent between any mapping that does not increase the value of vetoing for a low-cost deviator. That is, any signal that ensures $p_2(\sigma_i^{epic}{=}l) \geq 1 - r$ is incentive compatible. By announcing the $\Sigma_i^*$ we constructed under full commitment, the low type makes sure that the low signal realizes with probability 1.

Next consider the *high* type. It wants to pool with the *low* type in the most credible way. Suppose the high type deviates from announcing $\Sigma_i^*$, which we constructed under full commitment. Then the vetoing firm holds the off-path belief on the high type being the *high* type. The signal $\Sigma_i^*$ satisfies the designer's incentive constraints. □

## A.7 Proof of Proposition 5

*Proof.* The proof is constructive. Take any SSO, say $SSO^0$, and an equilibrium in which the SSO proposal is vetoed with positive probability on the equilibrium path. We call this the veto equilibrium. We first characterize the payoff distribution induced by the play of the veto equilibrium. Then, we show that there is an SSO, say $SSO^1$, which is unanimously accepted and leads to the same payoff distribution.

Firms might randomize their veto decision. Let $\xi(c)$ be the probability that the proposal $SSO^0$ is vetoed given type profile $c := (c_1, c_2)$. Moreover, $\xi_i(c_i)$ is the likelihood that type $c_i$ of firm $i$ vetoes proposal $SSO^0$ on the equilibrium path. The set of firms that vetoed, $V$, might be random.[30] After the veto decision, firms observe the set of firms that vetoed, say $\mathcal{V}$, and update to information structure $I^{\mathcal{V}}$, and payoffs realize according to $V_i(c_i|c_i, I^{\mathcal{V}})$. Taking expectations over all possible realizations of the set of vetoing firms, $\mathcal{V}$, the ex-ante expected continuation game conditional on a veto is a lottery $(P(\mathcal{V}), V_i(c_i|c_i, I^{\mathcal{V}}))$ defined over all $\mathcal{V}$. $P(\mathcal{V})$ is the on-path likelihood that a veto is caused by the set $\mathcal{V}$ and not by any other set of vetoing firms. Conditional that no firm vetoes, the information structure is $I^a$.

Now construct $SSO^1$. We invoke the revelation principle and assume, without loss of generality, that $SSO^1$ is a direct revelation mechanism to which firms truthfully report (conditional on acceptance). Its outcome function, i.e., the report-profile dependent distribution over shares and the disagreement outcome is as follows. If both firms accept $SSO^1$, then it replicates the lottery over payoffs that is induced in the equilibrium of the above described veto grand game (where the SSO was $SSO^0$).

We now construct a signaling device $\Sigma$ such that $SSO^1$ is implementable under full participation. By construction, $SSO^1$ is incentive compatible. What remains is to show that no firm has an incentive to veto $SSO^1$.

We construct the following signaling device $\Sigma_i : \{1, k\} \to \Delta(\{0, 1\})$ where $\sigma_i(c_i) = 1$ with probability $\xi_i(c_i)$ and 0 otherwise. When observing off-path behavior (i.e., a veto) by firm $i$, firm $-i$ believes that firm $i$ randomized over the entire type-space when reporting to $\Sigma_i$. Thus, it disregards the realization $\sigma_i$. Further, we choose the off-path belief on $i$ identical to the belief that firms attach to firm $i$ after observing firm $i$ unilateral veto in the veto equilibrium.

No firm $i$ has an incentive to veto the SSO proposal. If a firm vetoes the SSO proposal the signals $\Sigma_i$ provide the firm with the same lottery over information structures that it expects from a veto in the veto equilibrium. Participation, in turn, gives the same outcome as the veto equilibrium. No player can improve upon the outcome of the veto equilibrium by vetoing proposal $SSO^1$.

Finally, truthful reporting to $\Sigma_i$ is a best response as $\Sigma_i$ is payoff irrelevant on the equilibrium path. Thus, under $(SSO^1, \Sigma)$ an equilibrium with full participation in $SSO^1$ exists that implements the same outcome as the veto equilibrium. $\square$

[30] I.e., if firm $i$ vetoes then this set realizes as either $\{i\}$ or as $\{i, -i\}$

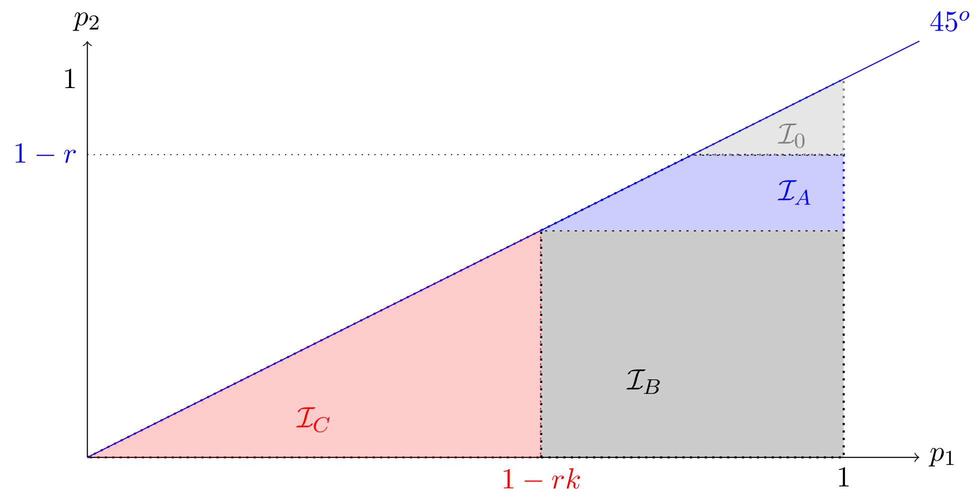


Figure 6: Partitioning the information set, given $p_1 \geq p_2$. Each partition corresponds to a type of equilibrium. See Lemma 1 for an analytical description.

# B Proof of Lemma 1

*Outline.* We solve the 2-player standards war for a general information structure. Lemma 1 is a corollary to Lemma 5. Lemma 5 in turn is a corollary to Siegel (2014). We state the arguments for completeness below in Appendix B.2.

## B.1 Equilibrium Strategies and Expected Payoffs in the All-Pay Auction

We first characterize the firm's equilibrium strategies which imply the equilibrium payoffs. We assume throughout wlog that $p_1 \geq p_2$.

An information structure in the general framework is $I = (p_1, p_2)$, $I$ can be in one of 4 sets. Figure 6 depicts the regions in the $(p_1, p_2)$ plane

$$\mathcal{I}_0 := \{I \in \mathcal{I} | r > 1 - p_2\}, \qquad \mathcal{I}_A := \{I \in \mathcal{I} | 1 - p_2 \geq r > (1 - p_2)/k\},$$
$$\mathcal{I}_B := \{I \in \mathcal{I} | (1 - p_2)/k \geq r > (1 - p_1)/k\}, \quad \mathcal{I}_C := \{I \in \mathcal{I} | (1 - p_1)/k \geq r\}.$$

Consider an all-pay contest with minimum investment $r$, and an environment in which firm $i$ might have marginal cost 1 or $k > 1$. From firm $-i$'s point of view $i$ has marginal cost 1 with probability $p_i$. Let $\Delta_i := \frac{1-p_i}{k}$ and assume the commonly-known information set $I$ lies in $\mathcal{I}$. Then, the equilibrium takes the following form, depending on $I$:

**Lemma 5.** **If** $I \in \mathcal{I}_0$,

- *Player 1 and 2, type* $k$*, invest zero,*
- *Player 1, type* $1$*, uniformly mixes on* $(r, 1]$ *with density* $\frac{1}{p_1}$ *and invests* $r$ *with probability* $1 - \frac{1+r}{p_1}$
- *Player 2, type* $1$*, uniformly mixes on* $(r, 1]$ *with density* $\frac{1}{p_2}$ *and invests zero with probability* $1 - \frac{1+r}{p_2}$.

*The expected interim utilities of each firm and type are* $0$.

**If** $I \in \mathcal{I}_A$,

- *Player 1 and 2, type* $k$*, invest zero,*
- *Player 1, type* $1$*, uniformly mixes on* $(r, p_2 + r]$ *with density* $\frac{1}{p_1}$ *and invests* $r$ *with probability* $1 - \frac{p_2}{p_1}$
- *Player 2, type* $1$*, uniformly mixes on* $(r, p_2 + r]$ *with density* $\frac{1}{p_2}$.

*The expected interim utilities of each firm and type are given by*

$$V_i(1) = 1 - r - p_2, \qquad\qquad V_i(k) = 0.$$

**If** $I \in \mathcal{I}_B$,

- *Player 1, type* $k$*, invests* $r$
- *Player 1, type* $1$*, uniformly mixes on* $(r, \Delta_2]$ *with density* $\frac{k}{p_1}$*, on* $(\Delta_2, \Delta_2 + p_2]$ *with density* $\frac{1}{p_1}$ *and invests* $r$ *with probability* $1 - \frac{1-rk}{p_1}$.
- *Player 2, type* $k$*, uniformly mixes on* $(r, \Delta_2]$ *with density* $\frac{1}{1-p_2}$ *and invests zero with probability* $1 - \frac{1}{k}\left(1 - \frac{r}{\Delta_2}\right)$.
- *Player 2, type* $1$*, uniformly mixes on* $(\Delta_2, \Delta_2 + p_2]$ *with density* $\frac{1}{p_2}$.

*The expected interim utilities of each firm and type are given by*

$$V_i(c_l) = \Delta_2(k-1), \qquad V_1(k) = (\Delta_2 - r)(k-1), \qquad V_2(k) = 0.$$

**If** $I \in \mathcal{I}_C$,

- *Player 1, type* $k$*, uniformly mixes on* $(r, \Delta_1]$ *with density* $\frac{1}{\Delta_1}$ *and invests* $r$ *with probability* $\frac{r}{\Delta_1}$
- *Player 1, type* $1$*, uniformly mixes on* $(\Delta_1, \Delta_2]$ *with density* $\frac{k}{p_1}$*, on* $(\Delta_2, \Delta_2 + p_2]$ *with density* $\frac{1}{p_1}$.
- *Player 2, type* $k$*, uniformly mixes on* $(r, \Delta_1]$ *with density* $\frac{1}{\Delta_2}$ *on* $(\Delta_1, \Delta_2]$ *with density* $\frac{1}{1-p_2}$ *and invests zero with probability* $(\Delta_2 - \Delta_1)\frac{k-1}{(1-p_2)} + \frac{r}{\Delta_2}$.
- *Player 2 type* $1$*, uniformly mixes on* $(\Delta_2, \Delta_2 + p_2]$ *with density* $\frac{1}{p_2}$.

*The expected interim utilities of each firm and type are given by*

$$V_i(c_l) = \Delta_2(k-1), \qquad V_1(c_h) = (\Delta_2 - \Delta_1)(k-1), \qquad V_2(c_h) = 0.$$

*Proof.* The equilibrium construction in each case follows that of Siegel (2014).

By Proposition 2 in Siegel (2014) it is without loss of generality (in terms of the outcome) to restrict ourselves to constructing one equilibrium. All equilibria are payoff equivalent.[31]

Let $e_i$ be the chosen investment of firm $i$. Given the strategies of its opponent, $s_{-i}$, and the information structure $I$, firm $i$ , type $c_i$, chooses investment $e_i$ that satisfies:

$$\frac{\partial Pr(e_i > e_{-i}|s_{-i}, I)}{\partial e_i} - c_i = 0.$$

Given this, strategies satisfy the local optimality condition for any information structure by construction.

Thus, what is left to prove is global optimality. This is done case by case:

**Case 1:** $I \in \mathcal{I}_A$

Global optimality follows from $p_1 \geq p_2 \geq 1 - rk$. If firm 1, type $k$ invests $r$, it receives payoff $1 - p_2 - rk < 0$. Similarly, if firm 2, type $k$ invests $r$, it receives payoff $1 - p_1 - rk < 0$. Player 2, type 1 receives payoff $(1 - p_1) + (p_1 - p_2) - r$ from investing arbitrarily above $r$, which is the same when investing until the top of the specified interval.

**Case 2:** $I \in \mathcal{I}_B$

Global optimality follows from $p_1 \geq 1 - rk > p_2$. If firm 1, type $k$ invests $r$, it receives payoff

$$\begin{aligned}
V_1(k) = (1 - p_2)\frac{(k-1)(1-p_2) + rk}{k(1-p_2)} - rk &= \\
\frac{(k-1)(1-p_2) + rk - r(k)^2}{k} &= \\
\frac{(k-1)(1-p_2) - rk(k-1)}{k} &= \\
(k-1)(\Delta_2 - r)&
\end{aligned}$$

which is larger than 0. Investing above $r + \epsilon$ instead of $r$ increases firm 1's probability to win by $(1 - p_2)\frac{1}{1-p_2}\epsilon$ at the cost of $k\epsilon$, which is negative since $k > 1$. By construction, firm 2, type $k$ is indifferent between investing arbitrarily larger than $r$ and zero, since any investment $e \in (r, \Delta_1)$ yields utility

$$\begin{aligned}
&(1 - p_1) + p_1\left(\left(1 - \frac{1 - rk}{p_1}\right) + (e - r)\frac{k}{p_1}\right) - ek \\
=&(1 - p_1) + p_1 - (1 - rk) - rk = 0
\end{aligned}$$

Player 1, type 1 receives payoff

$$(1 - p_2)\frac{(k-1)(1-p_2) + rk}{k(1-p_2)} - r = \Delta_2(k - 1)$$

from investing $r$, which is the same when investing until the top of the specified

[31]See below for the respective argument.

interval.

Player 2, type 1 receives payoff

$$(1-p_1)+p_1(1-\frac{p_2}{p_1})-\Delta_2=\Delta_2(k-1)$$

from investing the lower bound of the specified interval. This is the same payoff he receives when investing the upper bound of the specified interval.

**Case 3:** $I \in \mathcal{I}_C$

Global optimality follows from $1-rk > p_1 \geq p_2$. If firm 2, type $k$ invests $r$, it receives payoff

$$V_2(k)=(1-p_2)\frac{(k-1)(p_1-p_2)+rk^2}{k(1-p_2)}-rk=(p_1-p_2)\frac{k-1}{k}\geq 0.$$

By construction, firm 2, type $k$ is indifferent between investing arbitrarily larger than $r$ and zero:

$$(1-p_1)\frac{rk}{1-p_1}-rk=0$$

Player 1, type 1 receives payoff

$$(1-p_2)(1-(\frac{p_1-p_2}{k}\frac{1}{1-p_1}))-\Delta_1=\Delta_2(k-1)$$

from investing $\Delta_1$, which is the same when investing until the top of its specified interval.

Player 2, type 1 receives payoff

$$(1-p_1)+p_1(1-\frac{p_2}{p_1})-(\Delta_1+\frac{p_1-p_2}{k})=\Delta_2(k-1)$$

from investing the lower bound of the specified interval. This is the same payoff it receives when investing the upper bound of the specified interval.

□

## B.2 Adaptation of the Siegel (2014) framework

*Outline.* First, we restate central arguments of the all-pay auction from Siegel (2014) adapted to our notation. Second, we restrict the set of possible equilibrium outcomes using these arguments. Third, we establish piecewise linearity. Then, we characterize the different regimes.

**Lemma 6** (Siegel (2014))**.** *In a 2-firm all-pay contest with finite, independently drawn types and a minimum investment the following statements hold:*

*(i) Every equilibrium is monotonic. All monotonic equilibria are payoff equivalent.*

*(ii) There is no positive investment level at which both firms have an atom. If a firm has an atom, the atom is either at* 0 *or* $r$*.*

*(iii) If some investment level strictly above $r$ is not a best response for any type of one firm, no weakly higher investment level is a best response for* any *firm.*

*(iv) The intersection of the equilibrium investment levels of two different types of the same firms is at most a singleton.*

*(v) No firm ever invests more than $1/c_i$.*

*Proof.* See Lemma 1 and 2 in combination with Proposition 2 in Siegel (2014). □

By (i) it suffices to characterize one equilibrium. (ii) implies that some firm and some type earns 0 profits. The fact that types are ordered implies that it is a type-$k$ cost firm. By (iii) the two type-1 cost firms have the same upper bound on their equilibrium investment levels and thus the same payoffs. Finally, (iv) together with (iii) implies that it is sufficient to characterize the positive investment strategies up to a constant, as there are no "holes." Together with (ii), firms' equilibrium strategies are distributions with support on $0 \cup (r, \bar{e}]$ for some $\bar{e}$. Firms do not have a mass point on $(r, \bar{e}]$ . Moreover, $\bar{e} \leq 1/c_i$ where the last inequality follows from (v).

Consider such an equilibrium for any information structure $I$. Take any two levels $e_i$ and $e_i'$ in type $c_i$'s equilibrium support. Optimality requires

$$\frac{Pr(e_i > e_{-i}|I) - Pr(e_i' > e_{-i}|I)}{(e_i - e_i')} = c_i. \tag{3}$$

Thus, firm $-i$'s equilibrium investment distribution is differentiable with constant density. Let $F_{-i,c_{-i}}$ denote type $c_{-i}$'s cumulative distribution function, then $Pr(e_i > e_{-i}|I) = p_{-i}F_{-i,1}(e_i) + (1-p_{-i})F_{-i,k}(e_i)$. By property (iv) of Lemma 6 either $F_{-i,1} = 0$ or $F_{-i,k} = 1$ and by (iii) and Equation (3) the density at the highest equilibrium investment level is $f_i = 1/p_i$. The same holds true for any part of the intersection of the equilibrium support of the cost-1 types of firm 1 and 2.

We can now characterize the different regimes. Take regime $\mathcal{I}_0$, i.e., $r > 1 - p_2$. The likelihood that firm 2 invests on the interval $(r, 1]$ is smaller than 1. Thus, by (v) and (ii) of Lemma 6 it has an atom at $r$ or 0. Since $p_1 > p_2$ the same holds for firm 1. Yet, by (ii) *some* firm has an atom at 0. Thus, by (iii) rents are fully dissipated.

In regime $\mathcal{I}_A$ we have that $r < 1 - p_2$. Firm 2 type 1 invests on the interval $(r, \bar{e}]$ for some $\bar{e} < 1$. At the same time $r > (1 - p_2)/k$ such that firm 2 type $k$ can be successfully deterred. Only type-1 cost firms invest a positive amount and firm 1 uses its residual mass for investment at $r$, it wins with the likelihood that firm 2 is the $k$-cost type. Both type-1 cost firms make (the same) positive profits, type-$k$ cost firms make no profit.

In regime $\mathcal{I}_B$ the minimum investment is low enough such that a type-$k$ cost firm 1 investing $r$ would make positive profits if type-$k$ cost firm 2 remains out of the contest, but not vice versa. Thus, both type-$k$ cost firms cannot be deterred from the contest. In equilibrium all types and firms participate. Firm 1 has an atom at $r$ and firm 2 has an atom at 0. Consequently all but type-$k$ cost firm 2 expect positive profits. The expected payoff becomes less responsive to changes in $p_2$ because type-$k$ cost firm 2 is expected to invest a positive amount, (iv) provides the remaining argument.

Finally, in regime $\mathcal{I}_C$, firm 2's incentives to participate increase (compared to regime $\mathcal{I}_B$) as firm 1 becomes ex-ante weaker. In response type-$k$ cost firm 1 increases its expected investment which decreases its expected payoff. As $p_i$ goes to 0 both high cost participants increase their investment until at $p_i = 0$ payoffs reach (the complete information result of) full rent dissipation.

# C Other Types of Standards Wars

## C.1 Lottery Contests

Here we show that our findings extend to lottery contests (Tullock, 1980). We use the same model as in the main text but with a lottery contest and without a reserve price (or a sufficiently low reserve price) for tractability.

**Contest Success Function.** In a lottery contest, winning the standards war is random, conditional on the firms' investment levels. Assume that there is no reserve price, so $r = 0$. Let $e_{-i}(c_{-i}; (1, p_{-i}))$ be firm $-i$'s equilibrium investment when firm $-i$ is equipped with cost $c_{-i}$ and the information structure is $I = (1, p_{-i})$. Consider the case in which all types invest a positive amount in equilibrium ($\Leftrightarrow k \leq 4$) regardless of the type distribution. To shorten notation, let $\underline{e} := e_{-i}(k; (1, p_{-i}))$ and $\overline{e} := e_{-i}(1; (1, p_{-i}))$. Firm $i$'s problem becomes the following:

$$\max_{e_i} p_{-i} \frac{e_i}{e_i + \overline{e}} + (1 - p_{-i}) \frac{e_i}{e_i + \underline{e}} - e_i$$

Firm $-i$ faces the following problem:

$$\max_{e_{-i}} \frac{e_{-i}}{e_{-i} + e_i^*} - c_i e_{-i}$$

Here, $e_i^*$ is firm $i$'s optimal effort selection. Following, for example, Denter, Morgan, and Sisak (2021) or Zhang and Zhou (2016), we can derive the optimal effort levels in that case:

$$\begin{aligned} e_i^* &= \left( \frac{p_{-i} + (1 - p_{-i})\sqrt{k}}{1 + p_{-i} + (1 - p_{-i})k} \right)^2, \\ \overline{e} &= \sqrt{e_i^*} - e_i^*, \\ \underline{e} &= \sqrt{e_i^*/k} - e_i^* \end{aligned}$$

Plugging them into $i$'s payoffs delivers the following:

$$v_i(1;p_{-i}) = p_{-i}\frac{e_i^*}{e_i^* + \overline{e}} + (1-p_{-i})\frac{e_i^*}{e_i^* + \underline{e}} - e_i^*$$

**Informational Punishment.** Deriving general conditions is difficult, as $v_i(1;p_{-i})$ is a complicated object to analyze. However, if we restrict our attention to the case in which $k = 4$, the expected payoff for the vetoing firm $i$ is:

$$v_i(1;p_{-i}) = \frac{(4-3p_{-i})(2-p_{-i})^2}{(5-3p_{-i})^2}$$

The second derivative is:

$$\frac{\partial^2}{\partial p_{-i}\partial p_{-i}} v_i(1;p_{-i}) = 2\frac{(3p_{-i}-8)}{(3p_{-i}-5)^4} < 0$$

Thus, the vetoer's payoff is concave in $p_{-i}$, which implies that informational punishment is beneficial. For concreteness, consider the case in which $p_1 = p_2 = p = 9/25$. Then a standards war is inevitable without informational punishment because

$$v_i(1;9/25) = 122713/240100 \approx 0.51 > 1/2.$$

Now consider informational punishment that fully discloses types. That implies that we obtain the following:

$$\begin{aligned} v_i(1;0) &= 16/25, \\ v_i(1;1) &= 1/4, \\ \rho(\sigma_{-i} = l) &= p \end{aligned}$$

But then coordination is possible because

$$v(1;\Sigma^*) = 9/25\ v_i(1;1) + 14/25\ v_i(1;0) = 1121/2500 \approx 0.45 < 1/2.$$

Thus, in a lottery contest, informational punishment can be beneficial even absent a minimum investment.[32]

## C.2 Tournaments

Here we show our findings are robust to an alternative specification in which we consider the standards war as a tournament.

[32] In fact, concavity of $v_i(1;p_{-i})$ is not unique to our chosen specification but (at least numerically) robust to other values of $k$ provided we have an interior solution. We conjecture that if the high-cost type stays out of the competition for some values of $p_{-i}$ (which happens when $k > 4$), the effect becomes even stronger for the same reasons as in the frictionless contest in the main text.

**Tournament.** As before, there are two firms. However, in this example it suffices to have one-sided private information (see below for a discussion). Firm 1 has no private information, $\theta_1 = \underline{\theta}$, while firm 2 can be of two types $\theta_2 \in \{\overline{\theta}, \underline{\theta}\}$. The likelihood of being type $\underline{\theta}$ is $p$. The standards war in this example is a (Lazear and Rosen (1981)-inspired) tournament. Each firm select an investment level $e_i > 0$ that translates to an output $q_i = e_i + \varepsilon_i(\theta_i)$, where $\varepsilon$ is 'noise'—a random variable that depends on the type $\theta_i$. Firm $i$ wins the standards war if

$$q_i \geq q_{-i} \Leftrightarrow e_i - e_{-i} \geq \varepsilon_{-i}(\theta_{-i}) - \varepsilon_i(\theta_i).$$

Define $\Delta^{\theta_2} := \varepsilon_2(\theta_2) - \varepsilon_1(\underline{\theta})$, which itself is a random variable. To keep the algebra straightforward we make distributional assumptions directly on $\Delta^{\theta_2}$. We assume that if both firms have the same type, $\theta_2 = \underline{\theta}$, then $\Delta^{\theta_2}$ is distributed according to

$$F_{\underline{\theta}}(\Delta) = \begin{cases} 0 & \text{if } \Delta \leq -2 \\ (x+2)/4 & \text{if } \Delta \in [-2, 2] \\ 2 & \text{if } \Delta > 2 \end{cases}.$$

Otherwise it is distributed according to

$$F_{\overline{\theta}}(\Delta) = \begin{cases} 0 & \text{if } \Delta \leq -1 \\ (x+1)^2/4 & \text{if } \Delta \in [-1, 1] \\ 1 & \text{if } \Delta > 1 \end{cases}.$$

The distribution function $F_{\underline{\theta}}(\Delta)$ characterizes an on-par tournament. The mean is 0 implying that both firms have the same likelihood of winning if both firms make the same investment. However, there is uniform noise around the outcome so that the actual winner depends on the realization of $\Delta$. The variance is 4/3.

The distribution function $F_{\overline{\theta}}(\Delta)$ characterizes an asymmetric tournament. The mean is 1/3 implying that firm 2 is ceteris paribus more likely to win—firm 2 is stronger because the noise works in its favor. In addition, the noise is not uniform but skewed towards favoring firm 2. The variance is 2/9 and thus smaller than in the on-par case.

The cost of investment is quadratic, identical across types and given by $c(e_i) = e_i^2/2$.

Assume Firm 1's decision is $e_1^*$. Then firm 2 type $\theta_2$ solves

$$\max_{e_2} 1 - F_{\theta_2}(e_1^* - e_2) - \frac{e_2^2}{2},$$

Likewise assume that firm 2, type $\overline{\theta}$ ($\underline{\theta}$) selects $\overline{e}$ ($\underline{e}$). Firm 1 solves

$$\max_{e_1} p(F_{\underline{\theta}}(e_1 - \underline{e})) + (1-p)F_{\overline{e}}(e_1 - \overline{e})) - \frac{e_1^2}{2}.$$

First-order conditions are

$$\begin{aligned}
f_{\overline{\theta}}(e_1^* - \overline{e}) &= \overline{e}, \\
f_{\underline{\theta}}(e_1^* - \underline{e}) &= \underline{e}, \\
p f_{\underline{\theta}}(e_1^* - \underline{e}) + (1-p) f_{\overline{\theta}}(e_1^* - \overline{e}) &= e_1^*.
\end{aligned}$$

That implies

$$e_1^* = p\underline{e} + (1-p)\overline{e},$$

and thus

$$\begin{aligned}
e_1^* - \overline{e} &= p(\underline{e} - \overline{e}) & \qquad e_1^* - \underline{e} &= (1-p)(\overline{e} - \underline{e}) \\
f_{\overline{\theta}}\Big(p(\underline{e} - \overline{e})\Big) &= \overline{e}, & f_{\underline{\theta}}\Big((1-p)(\overline{e} - \underline{e})\Big) &= \underline{e}.
\end{aligned}$$

Since $f_{\underline{\theta}} = 1/4$ it is immediate that

$$\underline{e} = \frac{1}{4}.$$

Plugging into $\overline{\theta}'s$ first-order conditions and solving for $\overline{e}$ implies

$$\overline{e} = \frac{p+4}{4(2+p)},$$

and thus

$$e_1^* = \frac{p+4-2p}{4(2+p)}.$$

The equilibrium winning probabilities are

$$F_{\underline{\theta}}((1-p)(\overline{e} - \underline{e})) = \frac{1}{2} + \frac{1-p}{8(2+p)}$$

and

$$F_{\overline{\theta}}(p(\underline{e} - \overline{e})) = \frac{1}{4}\left(\frac{4+p}{4+2p}\right)^2.$$

Substituting into firm 1's equilibrium payoff we obtain

$$\begin{aligned}
V_1(p) &= p(F_{\underline{\theta}}(e_1 - \underline{e})) + (1-p)F_{\overline{e}}(e_1 - \overline{e})) - \frac{e_1^2}{2} \\
&= \frac{p}{2}\left(1 + \frac{1-p}{4(2+p)}\right) + \frac{(1-p)}{4}\left(\frac{4+p}{2(2+p)}\right)^2 - \frac{1}{2}\left(\frac{4+p-2p}{4(2+p)}\right)^2.
\end{aligned}$$

The second derivative with respect to $p$ is

$$\frac{\partial^2}{\partial p \partial p} V_1(p) = \frac{p-7}{4(2+p)^4}.$$

The two polar cases are

$$V_1(p=1) = \frac{15}{32}$$

and

$$V_1(p=0) = \frac{1}{8}$$

**Informational Punishment.** The second derivative above is negative for all $p$. Thus, the payoff $V_1(p)$ is strictly concave on the entire domain.

What remains is to check if a standards war is inevitable in the first place for some (but not all levels of $p$). Using our off-path belief putting full mass on the strong firm 2, i.e., $p = 0$, in this setting we obtain $\overline{e}(p=0) = 1/2$, $F_{\overline{\theta}}(p(\underline{e} - \overline{e})) = F_{\overline{\theta}}(0) = 1/4$ and

$$V_2(p=0) = \frac{3}{4} - \frac{1}{8} = 5/8.$$

Since $V_1(p)$ is concave and increasing in $p$ it suffices to evaluate $V_1(1) = 15/32 > 3/8$ and $V_1(0) = 1/8 < 3/8$. Thus for a sufficiently high $p$ a standards war is inevitable. By strict concavity the convex envelope of $V_1$ is strictly below $V_1(p)$ for all $0 < p < 1$. Thus there exists an interval $[p', p'']$ with $p'' > p'$ such that informational punishment ensures cooperation that otherwise could not be sustained.

**Discussion.** In this part we took a different approach to model a standards war. Here the private information is not in the cost, but instead about the distribution of the added noise. Moreover, different from the main text, one-sided private information is sufficient. The reason is that weak firms have an incentive to participate. They suffer from an unfavorable noise distribution yet wins are possible even at low investment levels. In the noiseless contest in the main text, high-cost firms instead always have an incentive to immediately concede against a stronger competitor.

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