Persuading to Participate: Mechanism Design with Informational Punishment*

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Abstract

We consider firms contemplating to coordinate on a standard in the shadow of a given market mechanism. Firms either cooperatively coordinate on the standard or a market solution emerges, that is, a standard war determines the outcome. We model coordination as a mechanism-design problem where a firm's veto to participate triggers the standard war. Participation constraints are demanding and full participation is not always optimal. A designer has access to informational punishment if she can commit to release information about *complying players*, even absent of full participation. Optimal informational punishment relaxes the participation constraints and persuades all players to participate.

1 Introduction

Industries operating in two-sided markets typically consolidate to a *de-facto standard* eventually, that is, a platform that all parties use for their interaction. If the standard is not imposed by a regulator, there are, broadly speaking, two ways how industries set their standard. Either the competitors cooperate via a *standard-setting organization* (SSO) and coordinate on the standard, or market forces determine the outcome. In the latter case, the standard emerges as the result of a standard war among firms.

In this article we use a mechanism-design approach to model SSOs. In particular, we view an SSO as a mechanism that has the power to implement any standard conditional on *all* firms respecting the SSO's authority by participating. However, firms do not need

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to honor an SSO. A firm that vetoes an SSO can enforce the *market solution*, that is, the standard is determined through a standard war.

Within this framework we address two questions. First, why and when do firms veto the SSO although the SSO involves fewer inefficiencies than the market solution? Second, how can we augment the designer's toolbox such that all firms find it optimal to participate?

As an example consider the format war between the blue-ray disc foundation and the HD DVD promotion group. Both parties failed to agree on a SSO to cooperatively set the standard. Instead they opted for the market solution. The market solution involved investments on both sides and eventually determined a winner, the blue-ray disc, which became the new standard for high-definition optical discs.

Why did the parties fail to avoid the inefficient standard war? One explanation is that both firms had private information about their prospects of the market solution. In particular, both may have been sufficiently optimistic that their product is likely to prevail in the market. As a consequence a format war was unavoidable. More strikingly, this mutual optimism may have been present among fully rational firms holding a common prior.

The reason for such mutual optimism is that both parties receive a positive signal about their own capabilities in a standard war, but are less optimistic about their competitor's capabilities. Thus, when calculating their best-responses both firms put little weight on facing a strong competitor. For the design of the SSO, in turn, that optimism means that both firms expect a favorable outcome of the procedure, something the SSO can at most grant one of the two. As a consequence, a strong firm has an incentive to reject any SSO mechanism that specifies the procedure upon *mutual acceptance*.

To overcome such coordination failure imagine the following. The SSO can ex-ante commit to release information about complying firms, even if some firm publicly rejects participation. That is, despite being unable to interfere with the market directly, the SSO can interfere with the information structure. Releasing information about the *accepting firms* influences all – accepting and rejecting – firms' action choices in the market. Consequently, it affects the prospects of the market solution.

We call information revelation that aims at deterring firms from vetoing an agreement *informational punishment*. We show that a firm contemplating to veto the agreement is effectively threatened by informational punishment. Threatening to release information about other firms' private information is sufficient to guarantee full participation in any mechanism because informational punishment decreases every firm's outside option.

Granting the designer access to informational punishment has a set of additional attractive features. Informational punishment separates the signaling effect of a veto from the outcome of participation. That is, informational punishment itself exclusively affects the players' participation constraints but has neither a direct effect on the (expected) outcome of the mechanism nor on incentive compatibility. The reason is that informational punishment only operates off the equilibrium path.

Moreover, optimal informational punishment is reminiscent of techniques common in the literature on Bayesian persuasion. Using these techniques, we obtain simple expressions for the (relaxed) participation constraints if informational punishment is available. Finally, the relaxed participation constraints are easy to handle and allow us to solve the initial mechanism-design problem using well-documented techniques. Informational punishment is thus a simple and straight-forward approach to incorporate veto mechanisms into the existing mechanism-design framework.

Our approach is constructive. The mechanism designer ex-ante commits both to generate a random signal about the information it obtains from the participating players and to communicate its realization publicly. If players cannot commit to ignore the information, every player updates her belief accordingly once the information is revealed. A player's continuation strategy is then a best response to that belief. In principle the designer can freely pick any posterior belief as long as the set of all posteriors is Bayes' plausible with respect to the prior. Thus, the signal splits the prior information structure such that a deviator's expected payoff before receiving the information is the convex combination of the payoffs from the continuation play subsequent to each realization.

Despite operating only off the equilibrium path, informational punishment reduces the players' participation constraints by exploiting non-convexities in a player's *value of vetoing*, a function determining a player's expected payoff given any information structure. Our findings apply to a wide range of mechanisms including both settings in which the players can – upon acceptance – fully commit to the mechanism and settings in which the mechanism operates only as a coordination device that recommends players an action in the market mechanism.

The insights we obtain go beyond the specific example of a standard-setting organization. Our results apply to any situation in which coordination takes place in *in the shadow* of a market solution, and parties can credibly veto a candidate mechanism. Examples include, but are not limited to, market solutions in which players compete for a prize such as litigation, crowdsourcing, strikes or competition with differentiated products.

From the point of view of the players, all these market solutions are inefficiently costly. Thus, there is an incentive to reach a collusive agreement such as an out-of-court settlement, a collective agreement, or a collusive production plan. However, no player is forced to participate in the collusion mechanism and cannot be excluded from enforcing the market solution.

Often, a public veto of one of the players to the collusion mechanism leads to the breakdown of the entire mechanism. In out-of-court settlements full participation is typically mandatory. In many other collusive agreements a single whistle-blower may jeopardize the entire agreement.

Related Literature

In the first-part of our article we analyze a stylized model of a competitive industry looking to establish a standard. Absent of coordination on a standard-setting organization, firms compete through a market mechanism. We adopt the view of a market mechanism as the costly outside option to coordinating on a standard-setting organization from Farrell and Saloner (1985). Similar to them we model it as a contest between competing standards.

We follow Farrell and Simcoe (2012) and assume that firms may, in principle, coordinate on any standard-setting mechanism to avoid the costly market mechanism and that firms hold private information about their own patents. However, different to Farrell and Simcoe (2012), we are not primarily interested in the question whether the *optimal standard* arises. Instead, our focus is on the *standardization function* (Lerner and Tirole, 2015) of an SSO, that is, its ability to select between equally good alternatives.

In our example we thus assume that the private information is exclusively about the estimated cost of engaging in the market mechanism. The general model of Section 3, however, is flexible enough to easily incorporate other issues in standard setting.[1] Most important for our analysis is that the market solution potentially limits the set of implementable solutions. This feature occurs in most parts of the literature on standard setting.[2]

Methodologically, we study a mechanism-design problem in its most general sense (Myerson, 1982). Informational punishment, in particular, is related to Bayesian persuasion (see the literature following Kamenica and Gentzkow, 2011), a version of information design (Bergemann and Morris, 2016). In contrast to the Bayesian persuasion literature in which a designer actively persuades players to pick a certain action, informational punishment works via a more subtle channel. The designer persuades players to participate in the proposed mechanism by threatening to release information in the event of non-compliant behavior. Thus, informational punishment never occurs on the equilibrium path. Nevertheless, the threat alone allows to convexify the players' participation constraints in the sense of Aumann and Maschler (1995). That convexification in turn relaxes the participation constraints the designer faces. As a consequence, the pure availability of a communication channel increases the designer's options.

The articles by Gerardi and Myerson (2007) and Correia-da-Silva (2017) offer an alternative approach to a similar problem. They, too, consider unilateral veto rights. Both

[1]See Lerner and Tirole (2015) for a complete discussion of the role(s) of SSOs.

[2]In addition to the aforementioned, also the literature on SSOs as certification entities (Chiao, Lerner, and Tirole, 2007; Farhi, Lerner, and Tirole, 2013) acknowledges this role of the participation constraint.

articles solve the participation problem using a trembling device that triggers a spurious veto to overcome the adverse effects of off-path beliefs.

In our setup, a player's veto is publicly verifiable, and a trembling device cannot influence players' off-path beliefs or prevent a veto. Informational punishment focuses instead on the threat of strategic information release in situations that almost surely do not occur. Despite its irrelevance for on-path outcomes, the mere promise of such information release disciplines players to participate. Moreover, informational punishment has no direct influence on the on-path design of the mechanism. Therefore, it separates the mechanism's signaling function that ensures participation from the on-path allocation problem.

Our approach offers a rich set of applications beyond the standard-setting example. Results apply whenever the mechanism designer chooses from the class of veto-constraint mechanisms, but can send public or private signals. Notably, our approach does not rely on strong assumptions about the mechanism's outcome space. Thus, informational punishment is possible and relevant in many environments ranging from pure coordination mechanisms, where an outcome is a recommendation about the player's action in a given market mechanism, to traditional mechanism design, where an outcome is a physical vector of goods (often a transfers and a consumption good) and the market mechanism is entirely replaced by the designer's proposal whenever all players decide to participate.

In the literature on industrial organization these types of mechanisms can be found in collusion in auctions (McAfee and McMillan, 1992; Balzer, 2016), vertical relations (Hart and Tirole, 1990; McAfee and Schwartz, 1994), innovation (Lerner and Tirole, 2004, 2015), bail-outs (Bolton and Skeel, 2010; Philippon and Skreta, 2012; Tirole, 2012), or dispute resolution (Hörner, Morelli, and Squintani, 2015; Zheng, 2017; Balzer and Schneider, 2018). We offer a simple, yet powerful extension to the canonical setup to increase players' incentives to participate. Notably, the designer does not expect to pay the cost of punishing a deviator. Informational punishment becomes relevant only off the equilibrium path.

We contribute to the literature on veto-constraint mechanism-design problems (e.g. Cramton and Palfrey, 1995; Compte and Jehiel, 2009). Indeed, without informational punishment, full participation may not be optimal if a veto triggers a given Bayesian game among players. Celik and Peters (2011) provide an example where any optimal mechanism involves on-path rejection and the revelation principle fails. In addition they raise a similar concern for settings in which the designer acts as an informed principal (Maskin and Tirole, 1990, 1992). Our setting nests the model of Celik and Peters (2011), but in addition we allow for informational punishment. We show that once the designer has access to informational punishment, all of their concerns become obsolete. Once we have identified the optimal informational punishment strategy we can proceed using the classic tools of mechanism design including the revelation principle and the principle of inscrutability.

The remainder of this article is structured as follows: In Section 2 we use the standard-setting example to illustrate our main insights. In Section 3 we generalize these insights and provide our main result. We discuss the role of our crucial assumptions in Section 4 and conclude in Section 5. All proofs not provided in the main text are in the appendix.

2 Example: Competition Between Propietarian Formats

Before turning to the general model, we study a stylized example of two firms contemplating whether to establish a standard. Despite its simplicity the example conveys the intuition of the more general result which we state, discuss, and prove thereafter.

Consider two risk-neutral firms each equipped with the technology to develop a *format* that could become the standard platform in a two-sided market. It is common knowledge that only one format will finally prevail. The firm that owns the intellectual property rights on this product *wins* the competition and enjoys a payoff normalized to 1. An example is the market for high-definition optical discs and the rivalry between HD DVD promotion group's HD DVD and blue-ray disc foundation's Blue ray.

Market Solution

Each firm can invest in the distribution of her format, for example, by subsidizing film studios to produce in that format or by fostering the distribution of playback devices. Investment increases the chances that the format prevails. For simplicity we make the extreme assumption that the format of the firm with the highest investment prevails with certainty if that investment is larger than some minimum investment $r > 0$. Ties are broken at random. The old technology remains the standard and payoffs are 0 should both firms invest less than r. The minimum investment r captures, for example, the necessity to equip the film studios with some technology to produce in that new format.

Investment comes at marginal cost c_i. We assume that c_i is private information to firm i as it is related to the specifics of each firm's format. Simplifying further, we assume that the marginal costs are constant and can only take two values, that is, $c_i \in \{1, \kappa\}$ with $\kappa > 1$. The marginal costs are independently drawn. Let p_i^0 be the probability that firm i has marginal cost $c_i = 1$. Apart from the private marginal cost all specifics of the game are common knowledge.[3]

The market solution is thus an all-pay contest with reserve price. We assume without loss of generality $p_1^0 \geq p_2^0$, that is, firm 1's *expected* marginal cost of investment are lower.[4]

[3] Simplifying assumptions are for ease of exposition and clarity only. As we will see in Section 3, all we require for our main result is the existence of a market solution for any information structure.

[4] Other applications of the all-pay contest with reserve price abound. For example, crowdsourcing cam-

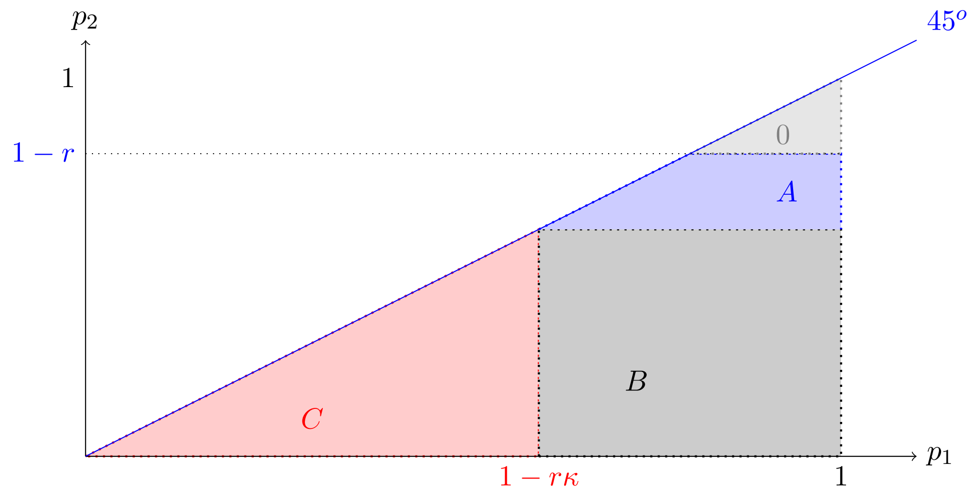

Figure 1: Partitioning the information set, given $p_1 \geq p_2$.

Let p_i be $-i$'s belief that firm i has marginal cost $c_i = 1$. Firms' strategies and thus their equilibrium payoffs depend on the relation between the two distributions, p_1 and p_2, the cost disadvantage of the high-cost firm κ, and the minimum investment r. We say that $I = (p_1, p_2)$ is the commonly-known information structure at the point in time where firms make their investment decisions. Given $p_1 \geq p_2$ the set of possible information structures, $\mathcal{I}$, can be partitioned in the following way

$$\begin{aligned}
\mathcal{I}_0 &:= \{I \in \mathcal{I} | r > 1 - p_2\}, \\
\mathcal{I}_A &:= \{I \in \mathcal{I} | 1 - p_2 \geq r > (1 - p_2)/\kappa\}, \\
\mathcal{I}_B &:= \{I \in \mathcal{I} | (1 - p_2)/\kappa \geq r > (1 - p_1)/\kappa\}, \\
\mathcal{I}_C &:= \{I \in \mathcal{I} | (1 - p_1)/\kappa \geq r\}.
\end{aligned}$$

Figure 1 illustrates the partitioning. Next, we summarize equilibrium payoffs.

Lemma 1. *Consider the game described above and take any two probability distributions*

paigns such as the inducement prize contests designed by the *X prize foundation*. Participants have to achieve a certain minimum goal *and* beat their opponents to win the prize. Another example is a litigation process when parties have to engage in certain minimum costs to enter the formal process such as fixed court fees. Finally, one could interpret electoral campaigning as such an all-pay contest provided that parties have to pay some fixed cost to participate in the first place.

$I = (p_1, p_2)$ with $p_1 \geq p_2$. Then, the equilibrium payoffs $V_i(c_i)$ are

$$V_i(1) = \begin{cases} 0 & \text{if } I \in \mathcal{I}_0 \\ 1 - r - p_2 & \text{if } I \in \mathcal{I}_A \\ (1 - p_2)\frac{\kappa-1}{\kappa} & \text{if } I \in \mathcal{I}_B \cup \mathcal{I}_C \end{cases}$$

$$V_1(\kappa) = \begin{cases} 0 & \text{if } I \in \mathcal{I}_0 \cup \mathcal{I}_A \\ (1 - p_2 - \kappa r)\frac{\kappa-1}{\kappa} & \text{if } I \in \mathcal{I}_B \\ (p_1 - p_2)\frac{\kappa-1}{\kappa} & \text{if } I \in \mathcal{I}_C \end{cases}$$

$$V_2(\kappa) = 0.$$

As in many contests, the weakest type of the (ex-ante) weakest firm receives zero expected payoff from participation. In addition, low-cost types of both players must obtain the same utility since the rules of the game inevitably lead to a common upper bound on the low-cost types' equilibrium investment support. The remaining intuition comes from observing Figure 1. Region 0 corresponds to a situation in which the likelihood of meeting a high-cost firm 2 is very small. Thus, a low-cost firm 1 has no incentive to gamble on such an event and therefore invests a lot to beat a low-cost opponent. This behavior leads to full rent dissipation. If the likelihood of meeting a high-cost firm 2 is intermediate (Region A), a low-cost firm 1 has an incentive to gamble on meeting a high-cost firm 2. That gamble results in a reduced investment which in turn leads to a reduction of the low-cost firm 2's investment leaving positive rents for low-cost firms. If the likelihood of meeting a high-cost firm 2 is relatively large (Region B and C) high-cost firms enter the contest, too. Their investment behavior depends on the likelihood of a high-cost firm 1. If this likelihood is small (Region B), a high-cost firm 2 is still reluctant to invest much as she most likely meets a low-cost firm 1. This results in relatively little investment by a high-cost firm 2 and thus large payoffs for a high-cost firm 1. If however, the likelihood of a high-cost firm 1 is similar to that of firm 2, both high-cost firms compete frequently reducing the payoff of a high-cost firm 1. Low-cost firms expected payoffs remain unchanged in regions B and C as the upper bound of the investment function is only determined by firm 2's type-distribution.

A Standard-Setting Organization

One potential way for firms to avoid the inefficient format war is to set up a standard-setting organization. That is, firms agree on a mechanism to resolve the format competition at little or no costs, save on the investments, and increase their (expected) payoffs. The simplest such resolution is a mechanism that distributes shares, x, of the standard's merits. That is, each firm receives an expected share x_i independent of her type. Such a pooling mechanism

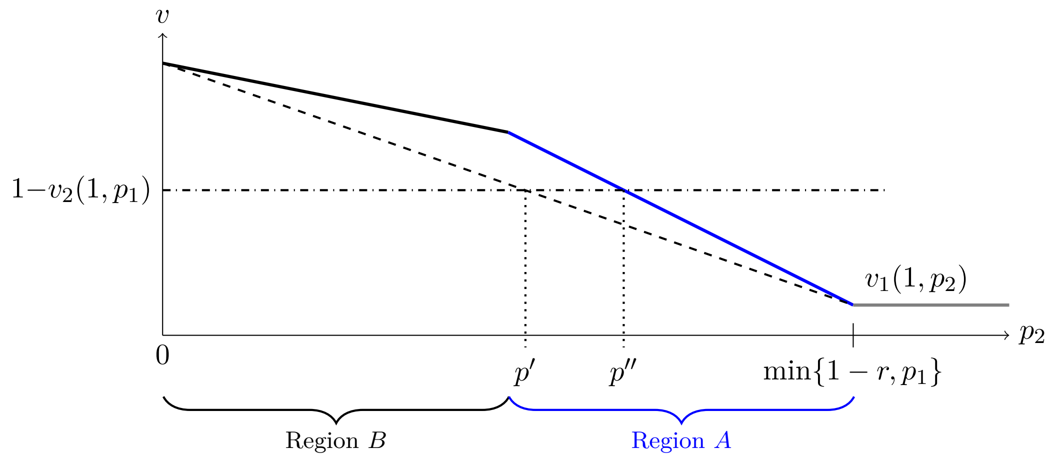

Figure 2: The value of vetoing for firm 1 given firm 2 assigns a probability p_1 to firm 1 having cost 1*. The dashed line denotes the function's convex closure. The dot-dashed depicts the residual resources after paying the minimum share to firm 2. For $\kappa = 5$, $p_1 = 1/3$ and $r = 1/6$, it follows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

is trivially incentive compatible but may violate a firm's participation constraint. Firms can always seek the market solution and initiate the format war. For the purpose of our example, we focus on the following game: Fix the above pooling mechanism. Both firms simultaneously decide whether to participate in the mechanism and if they do, firm i's format becomes the standard with probability x_i, such that $x_1 + x_2 = 1$. If at least one firm vetoes the mechanism, the firms engage in the format war.[5]

We want to sustain an equilibrium in which such a mechanism is successful with probability 1. To make full resolution as simple as possible, we assume that the non-deviating firm $-i$'s (off-path) beliefs upon observing a veto by her opponent i is a degenerate belief on i being the low-cost type. From the point of view of i this is the worst off-path belief. Therefore her participation constraint is as loose as possible (see Zheng, 2017, for a similar argument).[6]

The low-cost firm's value of vetoing, $v_1(1)$, is her expected payoff from the market solution under priors, i.e., $(p_1, p_2) = (p_1^0, p_2^0)$. The solid line in Figure 2 displays the value of vetoing as a function of the probability that firm 2 has low costs, $p_2^0 = p_2$. The simple mechanism outlined above can only work if the values of vetoing add up to less than the total surplus of 1. In the graph of Figure 2 this condition fails for any $p_2 < p''$ and, in the form presented above, the mechanism is not implementable.

Numerically, the following parameter values induce that situation.

[5] In light of the alternative interpretations above, the mechanism can represent a bidding ring, alternative dispute resolution, or within coalition bargaining in a multi-party government.

[6] In principle we can pick any off-path beliefs for the non-deviating firm. However, as the deviator cannot learn anything from deviating she keeps the prior belief.

Example 1. Let $\kappa = 5$, $p_2^0 = 7/24$, $p_1^0 = 1/3$ and $r = 1/6$.

Lemma 2. *Consider Example 1. Without informational punishment no full resolution mechanism exists.*

Proof. Let $\tilde{p}_1$ be low-cost firm 1's least-preferred, possible off-path belief *of firm 2 about firm 1*. One such worst belief is a degenerated belief on her being the low-cost type.[7] If firm 1 vetoes, both firms enter the contest given the belief profile $I = \{\tilde{p}_1 = 1, p_2^0\} \in \mathcal{I}_A$. Firm 1, type 1, receives the payoff $(1 - p_2^0 - r) = \frac{13}{24}$. Similar, the worst off-path belief from the perspective of low-cost firm 2, $\tilde{p}_2$, is a degenerate belief on her being the low-cost type. The belief profile $\{p_1^0, \tilde{p}_2 = 1\}$ is in (the mirror image of) Region A. Firm 2, type 1, receives the payoff $(1 - p_1^0 - r) = \frac{1}{2}$. Thus, a full-resolution mechanism requires a total payment of $1/2 + 13/24 > 1$. □

We now give the mechanism access to *informational punishment*: The mechanism ex-ante commits to release an informative signal about the non-deviating firm's message when one firm vetoes the mechanism. In addition, no firm can ex-ante commit to ignore available information. Using techniques from the Bayesian persuasion literature (Kamenica and Gentzkow, 2011), the mechanism can punish a deviator via an informative public signal. The designer uses informational punishment to relax the participation constraint and a full resolution mechanism is possible in the interval $[p', p'']$ in Figure 2.

The most severe informational punishment is obtained by constructing a convex closure of the value of vetoing. The firm's value of vetoing is then the value of this convex closure evaluated at the firm's prior belief.

Proposition 1. *Consider Example 1. If the designer has access to informational punishment a full-resolution mechanism exists.*

Proof. The proof is constructive and conveys the main intuition of informational punishment. The full resolution mechanism $\mathcal{M}^*$ is unanimously accepted, and implements the shares $(x_1, x_2) = (13/25, 12/25)$. The equilibrium of the game is the following: Both firms accept $\mathcal{M}^*$ and report their true types. If firm i vetoes, firm $-i$'s (off-path) belief is $\tilde{p}_i = 1$.

If firm 1 vetoes $\mathcal{M}^*$, the mechanism releases one of two possible signal realizations, $\{h_2, l_2\}$. The probability with which a signal realizes depends on firm 2's type report. The signals are constructed similar to those in Kamenica and Gentzkow (2011). Signal h_2 realizes only if firm 2 is the high-cost type and if so the contest is played given the belief profile $\{\tilde{p}_1{=}1, p_2{=}0\}$. The corresponding payoff to low-cost firm 1 is $4/5$. If the realization is l_2, the probability that firm 2 is the low-cost type equals $1 - r = 5/6$ and low-cost firm 1's expected payoff is 0. Signals have to be Bayes' plausible and thus the probability of signal

[7] Every probability mass weakly above p_2^0 is equally undesired.

realization l_2 is $\rho(l_2) = 7/20$. Consequently, low-cost firm 1's expected payoff is 13/25. Similarly, if firm 2 vetoes $\mathcal{M}^*$ she receives a signal from the set $\{h_1, l_1\}$. Signal h_2, too, is conclusive and signal l_1 results in a belief $p_1 = 1 - r = 5/6$. Bayes' rule implies that signal l_1 realizes with probability $\phi(l_1) = 6/15$ and the expected payoff of a deviating low-cost firm is 12/25. High-cost types receive a payoff of 0 when vetoing $\mathcal{M}^*$ and thus a full-resolution mechanism exists. $\square$

In the remainder of this article we generalize these results. We describe how informational punishment (i) ensures full participation and (ii) eases participation constraints. The intuition driving the result in this section is identical to that in the general setup.

3 Informational Punishment

Setup

Players and Information Structure. There are N players, indexed by $i \in \mathcal{N} := \{1, ..., N\}$. Each player has a private type $\theta_i \in \Theta_i$, with $\Theta_i \subset \mathbb{R}$ compact.[8] The state $\theta := \theta_1 \times ...\theta_N \in \Theta$ is distributed according to a commonly-known distribution function $F(\theta)$. Let $\theta_{-i} := \theta \setminus \theta_i$, and define the marginal $F_i(\theta_i) := \int_{\Theta_{-i}} F(\theta_i, d\theta_{-i})$ with support $supp(F_i) \subseteq \Theta \setminus \theta_i$. This formulation covers the prominent cases of finite or convex type spaces. An information structure I is a commonly-known joint distribution over the state θ. The only restriction we impose on I is that it is absolutely continuous w.r.t. F, that is, $supp(I) \subseteq supp(F)$. We refer to the information structure F as the *prior* and denote it by I^0. Given her type, θ_i, a player's *conditional information set* is $I(\theta_{-i}|\theta_i) = \frac{I(\theta_i, \theta_{-i})}{I_i(\theta_i)}$, with $I_i(\theta_i)$ the marginal of I. Following Bergemann and Morris (2016) the set $\mathcal{I}^0$ consists of all information structures for which I^0 is an expansion. That is, $I \in \mathcal{I}^0$ if and only if there exists a random variable $\widetilde{\Sigma}$ which maps types into distributions of signals such that the realization s together with $\widetilde{\Sigma}$ and I^0 implies I via Bayes' rule.

Basic Outcomes and Decision Rules. There is an exogenously given set of basic outcomes, $Z \subset \mathbb{R}^K$, with $K < \infty$. Player i values the basic outcome $z \in Z$ according to a Bernoulli utility function, u_i, defined over Z.

Let π be a decision rule, that is, a mapping from the type space into a probability measure over basic outcomes. Given any π, we denote the decision rule conditional on information structure I by π_I. The set of attainable outcomes given π is the product space $Z^\pi := \cup_I \{z \in supp(\pi_I)\} \subseteq Z$.[9] If Z^π is a compact metric space, a Borel-measurable decision

[8] None of our results depend on the one-dimensional type-space assumption. However, as this assumption is typically made in applications we impose it here.

[9] We abuse notation slightly because $supp(\pi_I)$ denotes a set of tuples (z, θ). By "$z \in$" we mean z is part of at least one such tuple.

rule π_I is *I-incentive compatible* if each player's von-Neumann-Morgenstern expected utility function, v_i, satisfies the following

$$\begin{aligned} v_i(\theta_i, I) &:= \int_{\Theta_{-i}} \int_{Z^\pi} u_i(z, \theta_i, \theta_{-i}) \pi_I(dz, \theta_i, \theta_{-i}) I^0(d\theta_{-i}|\theta_i) \\ &= \max_{\hat{\theta} \in \Theta_i} \int_{\Theta_{-i}} \int_{Z^\pi} u_i(z, \theta_i, \theta_{-i}) \pi_I(dz, \hat{\theta}_i, \theta_{-i}) I(d\theta_{-i}|\theta_i), \end{aligned}$$

almost everywhere conditional on I, that is, $\forall \theta_i \in supp(I_i)$.

Market Solution. In the absence of a mechanism, the non-cooperative play of a given *market mechanism* prevails and induces a decision rule, π^D. We assume that an equilibrium in the market mechanism exists for every I. The set of attainable outcomes given π^D is $Z^D \in Z$, a compact metric space. Equilibrium existence implies Borel-measurability of π_I^D and the revelation principle for Bayesian games implies that π_I^D is I-incentive compatible. We call the outcome implemented by the decision rule π^D the *market solution.*

Mechanism. Instead of participating in the market, players can participate in a given veto-constraint mechanism offered by a non-strategic party, the designer. Independently of the mechanism's outcome space, the equilibrium of the continuation game starting after every player accepted the mechanism induces a I^0-incentive-compatible decision rule, which is Borel-measurable. We identify the mechanism as a mapping from the players' type reports, m, into an I^0-incentive-compatible decision rule, π_{I^0}. The set of decision rules the designer can pick from might be restricted. We assume that $\forall I \; \pi_I^D \in \mathcal{I}^0$ is included in the designer's set of decision rules.[10]

The mechanism takes only place if *all* players accept it. If at least one player vetoes the mechanism by sending the empty message $\emptyset$, the mechanism is void, the identities of the vetoing players become known, and players turn to the market mechanism. Let I^{v_ι} be the information structure after observing a set of players $\iota \neq \emptyset$ veto. Then, the market solution is given by $\pi^D_{I^{v_\iota}}$.

In addition to π_{I^0} the designer proposes a signaling function Σ that maps messages of participating players into an element of a signal space $S \supseteq \Theta$. Importantly, no player can veto Σ. That is, a signal can be produced and communicated even absent full participation.

The designer selects and commits to a (joint) mechanism $\mathcal{M} = (\pi_{I^0}, \Sigma)$ at the beginning of the game. We call $\mathcal{M}$ *a mechanism with access to informational punishment.*

Timing. The timing is as follows: players learn their types and observe the choice of

[10] This assumption essentially allows the designer to at least act as a pure coordination device a la Myerson (1982). Thus, we exclude cases such as the following: *The outcome space of the designer's mechanism is the origin. That is, when players' participate in the mechanism, the basic outcome $z = 0$ will result with probability one, and players lose the possibility to play the market mechanism.*

$\mathcal{M}$. Then, they simultaneously send a message, $m \in \Theta_i \cup \emptyset$, to $\mathcal{M}$. If every player sends a non-empty message, then π_{I^0} is implemented. If one or more players send the empty message, the identities ι of these players become common knowledge and a signal $s \in S$ realizes according to Σ. Thereafter players update their information structure to $I_s^{v_\iota}$ and payoffs realize according to the market solution $\pi^D_{I_s^{v_\iota}}$.

In what follows we characterize the set of mechanisms implementable in a perfect Bayesian Nash equilibrium in the sense of Fudenberg and Tirole (1988).

Informational Punishment

A general concern in veto-constraint mechanism-design problems is that the revelation principle may not be valid as some allocations are implementable only if certain types of players reject the mechanism on the equilibrium path.

In light of our example, consider Figure 2. On-path rejection by firm 1 changes the prospects of vetoing for firm 2. Should she decide to veto, she is going to learn whether firm 1 had decided to veto or not. Since firm 1's veto decision happens on the equilibrium path, she forms rational beliefs about it. Thus, instead of playing the all-pay contest against a firm that is distributed according to the prior, firm 2 now plays either against a firm that decided to veto participation or a firm that accepted the mechanism. Both decisions influence firm 2's strategy. Such on-path vetoes significantly complicate the characterization of the optimal mechanism as they lead to failure of the revelation principle. However, if the designer has access to informational punishment all these considerations become obsolete.

Proposition 2. *It is without loss of generality to focus on mechanisms that ensure full participation when designing a mechanism with access to informational punishment.*

The formal argument is in the appendix. Its intuition is along the lines of the example in Section 2. On-path rejection of the mechanism is only beneficial to the designer if it relaxes the participation constraints. These participation constraints are a particular concern if the outside option to the mechanism is the equilibrium of a non-cooperative Bayesian game, such as the market solution. Then the value of that outside option is endogenous and depends on the information structure after a veto.

On-path vetoing relaxes these participation constraints in that it splits the prior information structure into two parts: (i) the information structure after veto; and (ii) that after acceptance. Both information structures are Bayes' plausible, that is, the prior is a *combination* of the two in the sense of Bergemann and Morris (2016). On-path rejection is beneficial if the information structure for an on-path veto can prohibit other *accepting players* from vetoing. Rejection can deter a veto if it relaxes the participating players' participation constraints.

A designer with access to informational punishment can induce such an information structure *without on-path rejection.* Instead, the designer promises ex-ante to send a partially informative signal about complying players' reports. Observing that signal is informative to all players. They update beliefs and adjust continuation strategies accordingly.

Any set of information structures that players can induce via on-path rejection in a mechanism without access to informational punishment can be replicated by the designer via an appropriate signaling function. The designer can relax the participation constraint through the choice of the signaling function at least as much as the player's can through the choice of on-path rejection. Consequently, it is without loss to focus on full-participation mechanisms.

A concern for the relevance of the result of Proposition 2 is, perhaps, that we assume that the designer can freely pick off-path beliefs under the perfect Bayesian equilibrium restriction. She can select any first-node off-path belief of the continuation game. Depending on the context and the application such equilibrium selection may not be reasonable. Using a refinement could instead *cause* the necessity of on-path vetoes in the first place because it limits the designer's equilibrium choice set.[11]

Our second finding is that the result of Proposition 2 is robust to the most common refinements in the mechanism-design literature. Specifically, whenever we refine off-the-equilibrium-path beliefs according a refinement criterion

$$(\star) \in \{\text{Perfect Sequential Equilibrium, Intuitive Criterion, Ratifiability}\},$$

then full participation remains optimal.

Proposition 3. *Suppose the solution concept is perfect Bayesian equilibrium with refinement concept* $(\star)$*. It is without loss of generality to assume full participation when designing a mechanism with access to informational punishment.*

Proposition 2 and 3 offer an alternative view on the benefits of persuasion. The classical approach of Kamenica and Gentzkow (2011) is to set up a mechanism that produces a Bayes plausible signal to influence the agent's action. Instead, the informational-punishment approach is to produce a Bayes' plausible signal that is only released if the agent does *not* take the desired action, i.e., when the agent does not participate in the designer's mechanism. Thus, agents are indirectly persuaded. We have shown that informational punishment can at least replicate the outcome that is achieved with a veto-constraint mechanism *without* access to informational punishment and overcomes the participation issues. While Proposition 2 and 3 therefore simplify the characterization of the optimal mechanism to the class

[11] Correia-da-Silva (2017) provides additional discussions on this issue and how it may interfere with the design of a mechanism.

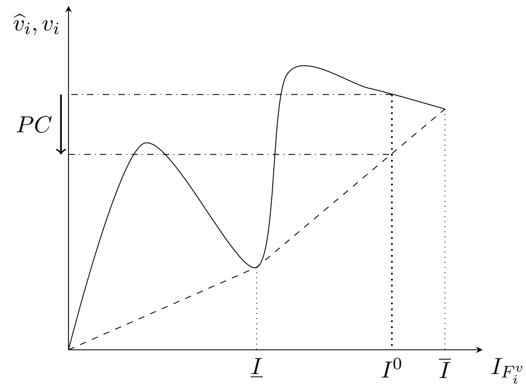

Figure 3: Value of vetoing and convex closure. *Given the prior information structure player i's participation constraint can be reduced by promising to realise a signal providing a mean-preserving spread over the prior and either changing the belief to either $\underline{I}$ or $\overline{I}$.*

of full-participation mechanisms, they do not directly address optimality within this class.

In the next step we address the effect of informational punishment beyond its ability to guarantee full participation. We show that including informational punishment (strictly) benefits the designer if in a setting without informational punishment (i) the participation constraint is binding for some player at the optimum, and (ii) the value of vetoing is (strictly) concave around the prior for this player. If both conditions are satisfied for some player, then informational punishment relaxes the participation constraints. If the type space Θ is finite it is easy to see that informational punishment relaxes θ_i's participation constraint to the value of the convex closure of $v(\theta_i, I_F^v)$. The approach is in line with concavification a la Aumann and Maschler (1995).

Let $\mathcal{I}_{F_i}$ be the set of all information structures in which the distribution over types of player i is fixed to F_i, and let $I_{F_i} \in \mathcal{I}_{F_i}$ denote a generic element in that set. Then, given any off-path belief F_i^v on a deviator i, informational punishment can reduce the value of vetoing to the largest function weakly smaller than the original v_i that is convex in $I_{F_i^v}$.

Corollary 1. *Suppose Θ is finite. The optimal mechanism with informational punishment is outcome equivalent to the optimal mechanism without informational punishment and a convexified value of vetoing,*

$$\hat{v}_i(\theta) := \max\{f : I_{F_i^v} \to \mathbb{R} | f \, \textit{convex and} \; f(I_{F_i^v}) \leq v_i(\theta, I_{F_i^v})\}.$$

The result follows directly from Proposition 2, but offers an alternative interpretation: Given any function v_i and a mechanism-design problem with access to informational punishment, we can reduce each player's participation constraint at no loss to $\hat{v}(\theta, I^0_{F_i^v})$ if we are only interested in the outcome of the optimal mechanism. Figure 3 provides a graphical intuition for the result.[12] In such a case the mere promise of persuasion reduces that player's *effective* value of vetoing.

Informed-Principal Problems

We now consider the following extension of our setting. Instead of a non-strategic designer, one of the players, say $i = 0$, proposes the mechanism. The setting becomes an informed-principal problem, where players $i = 1, ..., N$ are the agents. In problems of standard-setting organizations informed-principal problems occur for example when a firm tries to set up a patent pool around one of her own innovations. A key concept to solve informed-principal problems is the concept of inscrutability (see Myerson, 1983).[13]

Take a (partially) separating equilibrium of the grand game, that is, different types of player 0 propose different mechanisms. The revelation principle implies that the equilibrium play of this grand game induces a I^0 incentive-compatible decision rule. Suppose that all types of player 0 propose the mechanism that directly implements this decision rule, upon every agent's acceptance. Inscrutability holds if every agent accepts this mechanism.

As pointed out by Celik and Peters (2011) an agent's outside option might be non-linearly eased by being better informed about player 0's type. Consequently, the principle of inscrutability does not generally apply in a settings with endogenous outside options. Our final result states that if we allow player 0 to propose mechanisms with informational punishment, then the principle of inscrutability holds.

Proposition 4. *In an informed-principal setting, if the principal can propose mechanisms that allow for informational punishment, then the principle of inscrutability is satisfied.*

4 Discussion

In this section we discuss our most crucial assumptions, and their implications on our results.

Public Vetoes and Player's Commitment. The most crucial assumption is that players can publicly veto a mechanism, but are unable to commit to ignore information. An important consequence of this public veto ability is that the mechanism's power in the event of vetoing is limited. The simplest way to see how this assumption limits the mechanism's power is to consider a basic coordination mechanism a la Myerson (1982), where participation constraints are implicitly modeled by allowing players to send an empty

[12]In principle the result can be extended to a continuous type space at a large cost of notation and under some restrictions on the possible measures. We abstract from this for simplicity.

[13]The principle of inscrutability is essential for virtually all solution approaches to informed-principal problems (see for example Maskin and Tirole, 1990, 1992; Mylovanov and Tröger, 2014).

message. In such a mechanism, the designer sends recommendations about actions to the players who subsequently play a pre-defined game obeying these recommendations in equilibrium.

Any off-path behavior such as sending an empty message can be punished by the mechanism by committing to sending the *worst on-path recommendations* for the deviating player. Opponents do not know about the deviation, and obey the recommendation which punishes the deviator. Such a behavior is *not* possible in a veto-mechanism. Here, the deviator can credibly prove her veto. Thereby she triggers an off-path game and all players are aware that they are at an off-path node.

An equivalent assumption to that of verifiable non-participation is that players can at an *interim stage* commit to not participate, for example, by allowing public monitoring of their (non-existing) communication with the designer.

Meanwhile players cannot commit at any point in time to ignore publicly available information. A deviator would like to announce that she does not participate in the mechanism and ignores any information provided by the mechanism in the future. It is commonly known, however, that this announcement of ignorance is pure cheap talk. Then, even a non-participating player has an incentive to listen to the information once it is publicly available. Moreover, this is the unique behavior in equilibrium. If participating players thought the deviator ignores the information, the information would become nonstrategic and the deviator has an incentive to get informed.

The commitment structure we assume resembles many real-world scenarios where it remains optimal and possible to make a veto public even *after* it has been made. For example, in vertical contracts firms can make a public statement of non-negotiation that is legally binding or legal disputants can verify absence at a council meeting. At the same time we consider it unlikely for a player to be able to commit to ignoring information that is available and beneficial at an interim stage.

Designer's Power to Disclose Information. A second assumption we make is that the mechanism has the legal power to disclose information despite not being able to act otherwise. Thus, a necessity for informational punishment is that mechanisms are exempt from non-disclosure laws at least in off-path events.

Note that this assumption is substantially less demanding than that made in "trembling mechanisms" (Gerardi and Myerson, 2007; Correia-da-Silva, 2017). A trembling mechanism "fails" with positive probability although all parties vow to cooperate. Informational punishment, to the contrary, exclusively operates on an off-path event thereby not causing any violations of privacy with positive probability. Thus, all we require is the ability to commit to a signaling function prevailing when the game enters an off-path node.

In addition, we want to stress a metaphorical interpretation of the signaling function that serves as a motivation for the designer's ability to disclose information. That interpretation views the signaling function as an *experiment* on the players' reports (see Alonso and Câmara, 2016, for a similar interpretation). Suppose the designer cannot disclose the information herself. Instead she can provide a journalist with information what to investigate. Then the resulting report the journalist writes (and publishes) may serve as the signal to the players. Assuming that a variety of journalists exists, each having different working habits. Then, the designer has access to informational punishment through the choice of which information to provide to which journalist.

Market Solution. We impose neither strong assumptions on the market solution nor on the outcome space of the mechanism. Thus, when facing a mechanism-design problem it is without loss of generality to convexify the participation constraint and assume full participation, which in turn allows straight-forward application of well-known simplifications via the revelation principle or the principle of inscrutability. Furthermore, our approach is constructive and characterizes the structure of informational punishment that relaxes the participation constraints as much as possible.

5 Conclusion

We show that in the context of an SSO seeking to determine a standard in an industry, informational punishment can be a powerful tool to discipline privately informed firms to cooperate on setting the standard. That way, inefficiencies of standard wars can be reduced or even completely removed.

We model informational punishment as an extension to the classic mechanism-design framework. We allow the designer to send a public signal in case players fail to coordinate on a mechanism. The signal contains information obtained from participating players. We show that threatening players with such a signal relaxes their participation constraints and guarantees full-participation.

More generally, we characterize the set of attainable mechanisms in environments where the play of a Bayesian default game determines the agents' outside options to the mechanism. Any player is pivotal and can enforce that outside option. To rigorously characterize players' incentives to participate we model the outside option as an (arbitrary) Bayesian game. Informational punishment describes the designer's public signal in case players fail to coordinate on a mechanism.

Informational punishment reduces each player's value of vetoing to its convex closure with respect to the information structure, but does not effect incentive constraints. The informational punishment approach therefore allows to use standard mechanism-design methods to characterize the optimal mechanism in the presence of an arbitrary default game.

Our approach restores classic general results such as the revelation principle with full-participation and the principle of inscrutability. Our findings allow tractable solutions for a variety of applied problems. Veto mechanisms and Bayesian games as outside options are present in many areas of industrial organization and law and economics. In addition, they are relevant in the problem of political bargaining in the shadow of a popular vote, or in financial markets when creditors decide whether to act jointly or independently if the borrower is in distress.

In most of these applications institutions have the option to provide all relevant players with a public signal, which is a sufficient condition for access to informational punishment. In reality that access happens via the media, platforms such as wikileaks, or direct communication.

Using our approach, considering endogenously determined participation constraints does not come at a loss of tractability. We suggest that researchers apply mechanism design with informational punishment to analyze situations in which the strategic environment is partially beyond the designer's control. There our approach restores the powerful tools of mechanism design.

A Proofs

Proof of Lemma 1

Proof. A complete characterization of the equilibrium strategies is in the supplementary material to this paper. We omit them here and focus on the substance of the argument.

We use the following arguments taken from Siegel (2014) repetitively.

Lemma 3 (Siegel (2014))**.** *In a 2-player all-pay contest with finite, independently drawn types and a minimum investment the following conditions hold:*

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

(ii) There is no positive investment level at which both players 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 has to earn 0 profits. The fact that types are ordered implies that it has to be a firm of type κ. By (iii) the two low-cost firms have to have the same upper bound in their equilibrium investment levels and thus the same utilities. 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), we can restrict attention to equilibria in which all firms equilibrium investment levels have full support and no mass points on $(r, \bar{b}]$ for some $\bar{b} \leq 1/c_i$ where the last inequality follows from (v).

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

$$\frac{Pr(b_i > b_{-i}|I) - Pr(b'_i > b_{-i}|I)}{(b_i - b'_i)} = c_i. \tag{1}$$

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 $Pr(b_i > b_{-i}|I) = p_{-i}F_{-i,1}(b_i) + (1-p_{-i})F_{-i,\kappa}(b_i)$. By property (iv) of Lemma 3 either $F_{-i,1} = 0$ or $F_{-i,\kappa} = 1$ and by (iii) and equation (1) 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 regions. Take region 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 3 she has an atom at r or 0. Since $p_1 > p_2$ the same holds for firm 1, but by (ii) *some* firm, has to have an atom at 0 and thus by (iii) rents are fully dissipated.

In region A we have that $r < 1 - p_2$. Firm 2 type 1 invests on the interval $(r, \bar{b}]$ for some $\bar{b} < 1$. At the same time $r > (1 - p_2)/\kappa$ such that firm 2 type κ can be successfully deterred. Only low cost firms invest a positive amount and firm 1 uses her residual mass for investment at r, she wins with the likelihood that firm 2 is the high-cost type. Both low cost firms make (the same) positive profits, high cost firms make no profit.

In region B the minimum investment is low enough such that a high-cost firm 1 investing r would make positive profits if firm 2, type κ, remains out of the contest, but not vice versa. Thus both type κ players cannot be deterred from the contest. In equilibrium all types and players participate with firm 1, having an atom at r and firm 2, having an atom at 0. Consequently all, but firm 2, type κ expect positive profits. The expected utility becomes less responsive to changes in p_2 because firm 2 type κ is expected to invest a positive amount, (iv) provides the remaining argument.

Finally, in region C, firm 2's incentives to participate increase (compared to region B) as firm 1 becomes ex-ante weaker. In response firm 1, type κ increases her expected investment which decreases her expected payoff. As p_i goes to 0 both high cost participants increase their investment until at $p_i = 0$ payoffs reach the familiar complete information result of full rent dissipation. □

Proof of Proposition 2

Proof. The proof is constructive. We show that for every mechanism $\mathcal{M}$ without full participation there exists an alternative mechanism $\mathcal{M}^*$ that implements the same decision rule with full-participation.

Fix any equilibrium of the grand game for some arbitrary mechanism $\mathcal{M}$ that implements an I^0-incentive-compatible decision rule, π_{I^0}. Assume that at least one type of one player vetoes $\mathcal{M}$ along the equilibrium path in what we call the veto equilibrium. Let $\xi_i(\theta_i)$ be the probability that a player type θ_i vetoes and $A = \{i | \xi_i(\theta_i) = 0 \ \forall \ \theta_i \in \Theta_i\}$ be the set of players accepting $\mathcal{M}$ with probability 1 irrespective of their type.

We now construct a mechanism $\mathcal{M}^* = (\pi^*_{I^0}, \Sigma^*)$ providing the same expected payoff to each player as the equilibrium of $\mathcal{M}$.

The decision rule is chosen such that $\pi^*_{I^0} = \pi_{I^0}$ whenever all players accept the mechanism $\mathcal{M}^*$. Second, we construct Σ^* such that every player accepts $\mathcal{M}^*$. Define the random variable $S_{i,j} := \Theta_j \to \{0,1\}$ with associated probability $Pr(1|\theta_j) = \xi(\theta_j)$. Collecting the functions $S_{i,j}$ into a vector S_i defines another random variable. Then, let Σ^* be such that whenever player i vetoes random variable S_i realizes.

Finally, we need to show that there is a full-participation equilibrium given $\mathcal{M} = (\pi^*_{I^0}, \Sigma^*)$. That is, we need to show that there is an off-path belief about a deviating player i such that i prefers to participate in the mechanism. We differentiate between $i \in A$ and $i \notin A$.

First assume that the mechanism $\mathcal{M}^*$ is accepted by all but player $i \in A$. Consider the following off-path continuation game: If player i rejects the mechanism, then the other players hold the same off-path beliefs as in the case when $\mathcal{M}$ is vetoed in the veto equilibrium. The expected payoff at the point where player i makes her vetoing decision is the choice between the outcome $\pi^0_I(\cdot, \theta_i, \theta_{-i})$ when participating and a lottery over information structures induced by the signaling function Σ^*. However, she can – by construction – not prefer to choose that lottery over the expected outcome implemented by $\pi^*_{I^0}$: She is willing to participate under the veto-equilibrium in $\mathcal{M}$ and Σ^* replicates the post-veto distribution of that equilibrium. Thus, player i has an incentive to participate in $\mathcal{M}^*$.

Now, consider the situation of a player $i \notin A$. If such a player vetoes under $\mathcal{M}$, she faces opponents with an equilibrium belief according to the veto information structure $I^{v_i}_{\mathcal{M}}$. Under $\mathcal{M}^*$ the belief on a vetoing $i \notin A$ is at a first node off-the-equilibrium-path belief and we can specify it to be the same as $I^{v_i}_{\mathcal{M}}$ which is Bayes' plausible by construction. $\square$

Proof of Proposition 3

Proof. Ratifiability requires full-participation in the mechanism and therefore holds trivially, as the designer can always send a degenerate signaling function. It thus is without loss of generality to show full participation under refinement $(\star)' \in \{$Perfect Sequential Equilibrium, Intuitive Criterion$\}$.

Suppose the veto equilibrium of the mechanism $\mathcal{M}$ used in the proof of Proposition 2 satisfies refinement $(\star)'$. We want to show that the full-participation equilibrium given $\mathcal{M}^*$ satisfies the same refinement criterion. Two aspects are crucial to the candidate equilibrium. First, on-path and off-path (expected) outcomes in $\mathcal{M}$ and $\mathcal{M}^*$ coincide for any state θ whenever possible. Thus, in any state θ in which the mechanism is unanimously accepted the two mechanisms coincide and so do the credibility of their beliefs. Second, for any state θ for which an off-path belief exists under $\mathcal{M}^*$ but not under $\mathcal{M}$, the *off-path belief* of θ_i rejecting $\mathcal{M}^*$ coincides with the *on-path belief* after a veto of $\mathcal{M}$ by θ_i (only). As $\mathcal{M}$ satisfies $(\star)'$ on all its off-path beliefs, so does $\mathcal{M}^*$ whenever these off-path beliefs coincide. Now consider a type θ_i that vetoes with strictly positive probability in the equilibrium. This type is by construction indifferent between participating in $\mathcal{M}^*$ and vetoing the mechanism.

Thus, the constructed off-path beliefs put positive mass only on those types that *weakly prefer to deviate*, while obviously no such type *strictly prefers to deviate.* Thus, any off-path belief for type θ_i is credible in the sense of Grossman and Perry (1986) *and* off path beliefs do not violate the intuitive criterion. □

Proof of Proposition 4

Proof. Suppose there exists an equilibrium of the grand game such that different types of player 0 propose different mechanisms, E. Let M be the set of mechanisms that are proposed with strictly positive probability. Let $\xi_0^m(\theta_0)$ denote the probability that principal type θ_0 proposes mechanism $m \in M$.

This equilibrium play implements a I^0 incentive-compatible decision rule $\pi_{I^0}^E$ because of the revelation principle. Assume that at least one type of one agent vetoes at least some $m \in M$ on the equilibrium path. We refer to this equilibrium as the separating-and-veto equilibrium. For $i > 0$, let $\xi_i(\theta_i)$ denote the probability that type-θ_i agent vetoes. Moreover, $A=\{i|\xi_i(\theta_i)=0 \ \forall \ \theta_i \in \Theta_i\}$ is the set of agents that accept every $m \in M$ with probability 1 irrespective of their type.

We now construct a mechanism $\mathcal{M}^* = (\pi_{I^0}^E, \Sigma^*)$ which every agent accepts in a pooling equilibrium where every principal type proposes this mechanism. Thus, this proposal implements the same decision rule as the hypothetical (partially) separating equilibrium.

We construct Σ^* such that every agent accepts $\mathcal{M}^*$. For $j = 0$ and $i > 0$, define the random variable $S_{i,0} := \Theta_0 \to M$ with associated probability $Pr(m|\theta_0) = \xi_0^m(\theta_0)$. For any $i, j > 0$, define the random variable $S_{i,j} := \Theta_j \to \{0, 1\}$ with associated probability $Pr(1|\theta_j) = \xi(\theta_i)$. Collecting the functions $S_{i,j}$ into a list S_i defines another random variable. Finally let Σ^* be such that whenever player i vetoes random variable S_i realizes.

Finally, we show that no agent is better off by unilaterally vetoing the mechanism. That is, we show that for every agent i there exists an off-path belief the other players hold about i such that i prefers to participate in the mechanism.

First assume that the mechanism $\mathcal{M}^*$ is accepted by all but agent $i \in A$. Consider the following off-path continuation play: If agent i rejects the mechanism and $S_{i,0}$ realizes, then the other players hold the same off-path beliefs about her as in the hypothetical separation-and-veto equilibrium after player 0 proposed the mechanism $m = S_{i,0}$. At the point in time where agent i decides about participation, she thus compares two lotteries: The lottery $\pi_{I^0}^E$ with uncertainty over θ_{-i} prevails when accepting the mechanism. Rejecting the mechanism, however, triggers a lottery over information structures induced by the signaling function Σ^*. Given that agent i was willing to participate in every $m \in M$, and Σ^* replicates the post-veto distribution given the equilibrium under E, choosing the lottery can – by construction – not be preferred to $\pi_{I^0}^E$. Thus, player i has an incentive to participate.

Next consider the situation of a player $i \notin A$. The situation is similar for such a player, with the differences that a veto implies off-path beliefs on that player which are on-path beliefs in the veto equilibrium. $\square$

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B Online Appendix: Additional Material for the Proof of Lemma 1

Equilibrium Strategies and Expected Payoffs in the All-Pay Contest

We first characterize the player's equilibrium strategies which imply the equilibrium payoffs.

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

Lemma 4. If $I \in \mathcal{I}_0$,

- *Player 1 and 2, type κ, 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 player and type are 0.

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

- *Player 1 and 2, type κ, 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 player and type are given by

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

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

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

$$V_i(c_l) = \Delta_2(\kappa - 1),$$

$$V_1(\kappa) = (\Delta_2 - r)(\kappa - 1),$$
$$V_2(\kappa) = 0.$$

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

- *Player 1, type* κ*, 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* $\frac{\kappa}{p_1}$*, on* $(\Delta_2, \Delta_2 + p_2]$ *with density* $\frac{1}{p_1}$*.*
- *Player 2, type* κ*, 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* $(\Delta_2 - \Delta_1)\frac{\kappa-1}{(1-p_2)} + \frac{r}{\Delta_2}$*.*
- *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 player and type are given by

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

Proof. The equilibrium construction in each case follows essentially 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 as all equilibria are payoff equivalent.

Let e_i be the chosen investment of player i. Given the strategies of her opponent σ_{-i} (and the information structure I), player i , type c_l, chooses investment b_i that satisfies:

$$Pr'(b_i > b_{-i} | \sigma_{-i}, I) - c = 0.$$

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 $p_1 \geq p_2 \geq 1 - r\kappa$, :

If player 1, type κ invests r, she receives payoff $1 - p_2 - r\kappa < 0$. Similarly, if player 2, type κ invests r, she receives payoff $1 - p_1 - r\kappa < 0$.

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 $p_1 \geq 1 - r\kappa > p_2$:

If player 1, type κ invests r, she receives payoff

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

which is larger than 0. Investing above $r+\epsilon$ instead of r increases player 1's probability to win by $(1-p_2)\frac{1}{1-p_2}\epsilon$ at the cost of $\kappa\epsilon$, which is negative since $\kappa > 1$.

By construction, player 2, type κ is indifferent between investing arbitrarily larger than r and zero, since any investment $b \in (r, \Delta_1)$ yields utility

$$
\begin{aligned}
&(1-p_1)+p_1\left(\left(1-\frac{1-r\kappa}{p_1}\right)+(b-r)\frac{\kappa}{p_1}\right)-b\kappa \\
=&(1-p_1)+p_1-(1-r\kappa)+b\kappa-r\kappa-b\kappa = 0
\end{aligned}
$$

Player 1, type 1 receives payoff

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

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

Player 2, type 1 receives payoff

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

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: $I^i \in \mathcal{I}_C$

Global optimality follows $1-r\kappa > p_1 \geq p_2$:

If player 2, type κ invests r, she receives payoff

$$
V_2(\kappa) = (1-p_2)\frac{(\kappa-1)(p_1-p_3)+r\kappa^2}{\kappa(1-p_2)} - r\kappa = (p_1-p_2)\frac{\kappa-1}{\kappa} \geq 0.
$$

By construction, player 2, type κ is indifferent between investing arbitrarily larger than r and zero:

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

Player 1, type 1 receives payoff

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

from investing Δ_1, which is the same when investing until the top of her specified interval.

Player 2, type 1 receives payoff

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

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

□