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Article

Coordination and Private Information Revelation: Failure of Information Unraveling

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Abstract: This paper examines a persuasion game between two agents with one-sided asymmetric information, where the informed agent can reveal her private information prior to playing a Battle-of-the-Sexes coordination game. We find that in the presence of strategic uncertainty in coordination there exists an equilibrium where there is no 'unraveling' of information. We provide a purification argument for this mixed strategy equilibrium to strengthen the central result, which is robust to several extensions, including both-sided asymmetric information and imprecise information revelation.

Keywords: private information revelation; coordination; strategic uncertainty

JEL: C72; D82; L15

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1. Introduction

This paper examines the interaction between information revelation and coordination. To this end we consider a variant of the persuasion game where, following the disclosure stage, agents decide whether to coordinate or not. As with persuasion games, the central issue is whether agents with private information have an incentive to reveal their information or not. We shall find that the presence of strategic uncertainty regarding coordination possibilities leads to some interesting insights which add to the literature (in particular to the seminal contributions by [1] and [2]).

Coordination is of course central to much of economics. Beginning with the compelling example of [3] on coordination among two agents, various sub-disciplines of economics has investigated coordination games and their applications. Examples can be drawn from fields as diverse as industrial organization, e.g. agents coordinating on various actions like technology, entry, mergers and joint ventures; political economy, e.g. lobbying, and coalitional politics; and growth and development.

In the case of technology, standard formation in network industries is an area where issues of coordination have been discussed in detail ([4], [5]). In such industries standard formation is key to success, creating and expanding the market. In a large number of successful standards, coordination among competitors has driven the process, such as NTSC colour television standard (despite the vested interests of RCA and CBS) in the 1950s in the U.S., standardization of the CD technology with Sony and Philips pooling and licensing their patents, standardization of 56k modems, establishment of the GSM standard for mobile telecommunications, etc.

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Joint ventures and mergers, similarly, have to contend with coordination issues such as strategic uncertainty and have been analyzed in detailed in the literature on antitrust. For instance, for research joint ventures, [6] finds that ignoring costs of coordination in the formation of joint ventures incorrectly inflates the value of the partnership and that competition in R&D might yield a welfare enhancing outcome.

Coordination games are discussed extensively in the macroeconomics literature dealing with excessive aggregate responses to shocks. [7] provides a summary of macroeconomic models where strategic complementarities arise due to peculiarities in the production and demand functions, as well models where the presence of private information and search costs result in coordination failures and over-reactions to aggregative shocks. [8] discusses strategic complementarities in a multi-sector imperfectly competitive economy resulting in coordination failure.

Turning to the formal model, we consider a framework with two agents, call them A and B, with both having an "idea" of her own. They obtain a payoff from their own idea, as well as an additional amount in case there is coordination on a single idea. Further, the type of one of the agents, say agent A, is private information. We consider a two stage game where, in stage 1, agent A can reveal her type, and then in stage 2 they play a battle-of-the sexes game where they decide on which idea to adopt. In line with much of the literature on persuasion games, information is taken to be hard.

Our central result is that there exists an equilibrium where there is no revelation of private information. This non-revelation result is in contrast to the early literature on persuasion games which uses an unraveling argument to demonstrate that there would be full disclosure. Our analysis traces the non-revelation result to the possibility of strategic uncertainty over coordination possibilities. Thus this result adds to the subsequent literature that examines economic environments where the revelation argument needs to be qualified. One can mention, among others, [9], who finds partial revelation in the presence of costly revelation of private information; [10], who argue that in the presence of asymmetric information over the preference of the information providers there is no information revelation; and [11], who study sufficient conditions for complete revelation of private information, when such disclosure is a strategic choice. However, the latter rule out strategic uncertainty in coordination by abstracting from 'coordination equilibria', whereby there can be multiple pure strategy equilibria in the stage following information communication.

The intuition for the non-revelation result has to do with coordination possibilities in the second stage game. Why, for example, should an agent with a valuable private idea not want to reveal? We find that the non-revelation argument holds whenever the continuation game in the coordination stage involves strategic uncertainty, formalized through a mixed strategy equilibrium. An important aspect of the mixed strategy equilibrium in a coordination game is that, in order to keep the opponent indifferent between her two actions, a player has to play the action associated with a lower-payoff coordinated outcome with a higher probability than the action associated with a higher-payoff coordinated outcome. Letting θ denote the value of her own idea to agent A, if agent A reveals a relatively high θ, agent B becomes more aggressive in adopting her own idea, i.e.will choose B with a relatively high probability in the ensuing coordination game. Thus if an agent A with high valuation reveals her type, agent B will respond much more aggressively compared to the case when agent A does not (since in this case agent B's response will be based on the expected average value of agent A's type). Thus for such an agent A, non-revelation is optimal. Whereas if agent A has a relatively 'bad' idea, then agent A is more interested in coordination itself, rather than the identity of the idea on which coordination takes place. Therefore agent A has little to gain by revealing information and ensuring coordination on her own idea. She would rather ensure that coordination takes place on agent B's idea (B), since while she loses because B is selected, she more than makes up for it since the probability associated with coordination on B is much larger. Again she would prefer not to reveal.

Note that the non-revelation outcome involves agent B playing a completely mixed strategy in the coordination stage, with B's adoption of a mixed strategy reflecting her lack of knowledge regarding both

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A's type, as well as action. It has been argued, most notably by [12], that in the presence of coordination uncertainties, mixed strategies can help capture such uncertainties. In a similar vein, [13] argues that randomization in mixed strategies reflects the uncertainty in the mind of a player about the opponent's strategy, rather than a deliberate mixing of pure strategies.

It is natural to ask however if the non-revelation result is critically dependent on the fact that agent B plays completely mixed strategies in equilibrium. To that end we adopt a purification argument akin to Harsanyi's defence of mixed strategy equilibria ([14]), and examine a modified version of our baseline framework where agent B's type is also private information (though agent B cannot reveal her type as hard information). We find that the coordination game has an equilibrium where each B-type plays a pure strategy, with each B-type opting for technology B iff her valuation exceeds a critical cut-off. Interestingly, this strategy generates the same probability distribution over agent B's actions, as that under the mixed strategy equilibrium in our baseline framework. We then use this equilibrium to demonstrate that the non-revelation result holds in this framework as well, even though the coordination game does not involve any type of agent B playing mixed strategies.

The canonical game, however, has other equilibria. In particular, there exist equilibria with full disclosure. We find that information revelation obtains whenever the agents either play a pure strategy equilibrium, or a coordinated equilibrium in the coordination stage. These results suggest that the presence of strategic uncertainty is critical for non-revelation to occur.

Finally we go on to examine several extensions of the baseline model, e.g. allowing for both sided asymmetric information (where both agents can reveal hard information), as well as the the possibility of imprecise information revelation, demonstrating that the non-revelation result is robust to these extensions. Further, in case of mandatory disclosure of information, the overall probability of coordination on either A or B might be the same as, higher than or equal to that in the equilibrium with no information disclosure. The effect on coordination probability depends on the nature of the distribution of θ. The intuition for this is again driven by the property of the non-revelation equilibrium, with B playing a completely mixed strategy in a manner that raises the probability of achieving coordination for low values of $\theta < \hat{\theta}$ while reducing the probability of coordination for values of $\theta \geq \hat{\theta}$.

We believe that our model addresses some real-life examples of coordination in the presence of private information, where revelation of hard evidence is of paramount importance, such as information sharing in standards consortia. This paper thus restricts itself to revelation of hard evidence. It therefore ignores equilibria with cheap talk, as well the possibility of side-payments between agents (and therefore, mechanism design issues). In future work we would like to extend our framework to allow for cheap talk, as well as hard evidence. This class of games is more relevant in the context of firm entry with underlying conditions of natural monopoly, as discussed in [15] and [16]. We conjecture that the equilibrium set would be enlarged with the introduction of cheap talk, making the selection of equilibrium a more difficult task.

1.1. Literature Review

The early literature on voluntary disclosure of private information discusses complete unraveling of private information. [1], for instance, demonstrates full disclosure in a persuasion game involving a privately informed seller and an informed buyer. Similarly, [2] finds that unraveling holds for a single seller with no reputational concerns and with private information facing many buyers with no prior experience of the good, as long as the seller makes *ex post* verifiable claims, or can offer warranties, and beliefs are skeptical.

However, there are many environments where the incentive to reveal private information is limited. In the context of a buyer-seller exchange [9] shows that the unraveling result fails to hold in monopolistically competitive markets with costly disclosure of private information. [17] obtains a similar result when buyers are unsure about the existence of private information in the market. Further,

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[18] and [19] note that competition increases the amount of private information disclosed in market exchange.[1]

[10] on the other hand, qualifies the unraveling result in the context of an uninformed decision-maker who has to rely on information which is provided by interested parties. If the decision maker is fully informed, competition is not necessary for complete information revelation. However, in case the preference of the interested party is private information, competition itself is not sufficient for full disclosure. Finally, for accounting disclosures [22] shows that the context decides whether revelation will be complete, or incomplete.

None of these papers marry the problem of information revelation to the presence of strategic uncertainty in coordination. This is the precise problem investigated in our paper. Our paper is closest in spirit to [12] and [23]. We examine an asymmetric private information version of the complete information committee standardization game in [12]. [23] study a related framework with symmetric private information among all agents in the context of a war-of-attrition game. In both these papers however the focus is on the issue of standardization, rather than on information revelation. We, on the other hand, analyze the interaction between coordination uncertainty and private information.

Some papers, such as [24] and [25], show that even when there is a unique equilibrium in the second stage, unraveling fails. This paper contributes to the literature on both revelation of private information, as well as coordination games, the central contribution being the identification of strategic uncertainty in coordination as a reason for non-disclosure and the finding that complete non-revelation can obtain in a robust fashion. In our paper, the conditions in [24], [25] and [26] for a "worst case type" supporting full disclosure equilibrium is not satisfied by the continuation equilibrium payoffs of player 1, given that player 2 randomizes in the second stage.

2. The Model

Two agents A and B each have an idea/technology of their own, denoted A and B respectively. There is one-sided asymmetric information in that agent A has some private information regarding her own payoff from adopting A.[2] We analyze a two stage game with an initial information revelation stage, where agent A may or may not reveal her private information. This is followed by a version of the battle-of-the sexes game, where both the agents choose, simultaneously, whether to adopt their own idea, or to switch to the idea of the other agent. The outcome in stage 2 of course depends on the information revealed earlier, if any, in stage 1.

In case an agent adopts her own idea, she obtains a private benefit. She also obtains an additional coordination benefit in case the other agent coordinates on the same idea as well. In case she switches to the idea of the other agent, she obtains no private benefit, but will obtain the coordination benefit in case both choose the same idea.

Formally, agent A's private benefit from adopting A, denoted θ, is distributed over the compact, continuous type space $[\theta_l, \theta_h] \subset \mathbb{R}_+$ with distribution $F(\theta)$, where $F(\theta)$ is non-degenerate and strictly increasing. The exact realization of θ is however private information of agent A. Agent B's benefit from operating B, denoted b, is however deterministic. Further, both agents obtain a coordination benefit c in case they both choose the same idea.

The timing of the game is as follows:

[1] Empirical investigations regarding the effect of competition on revelation offer conflicting results [20] observe that intermediary agents in agricultural markets with limited competition do not voluntarily reveal private information. Further, despite competition there is no voluntary disclosure in the market for insurance plans offered by Health Maintenance Organizations (HMOs) ([21]).

[2] We focus on the case with one-sided asymmetric information as the motivating applications are for this case. We later argue in Section 5 that the results extend qualitatively to the case with both-sided asymmetric information.

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1. **Stage 1: Revelation:** Agent A decides whether or not to reveal her type θ. Agent A can either reveal her exact type by providing hard information, or decline to offer any information. The message space of A is, therefore, $M = [\theta_l, \theta_h] \cup \{\text{Not Reveal } \theta\}$. Thus the set of random messages, $\Delta(M)$, is given by $\Delta(M) = \{m | m \text{ is a probability distribution over } M\}$.
2. **Stage 2: Coordination:** The agents play a coordination game, where agent i chooses an action from $\{\text{Adopt } i, \text{Switch to } j,\ i, j \in \{A, B\}, j \neq i\}$. If both the agents choose to adopt their own idea, there is no coordination, with agent A obtaining θ and agent B obtaining b. On the other hand, if both the agents switch to the other's idea, then they both have a payoff of 0. If they coordinate on A, then the payoff vector is $(\theta + c, c)$, whereas it is $(c, b + c)$ if they coordinate on B.[3]

The payoff matrix for the stage 2 game is given in Table 1 below:

Table 1. Payoff matrix for the one-shot game

	Switch to A	Adopt B
Adopt A	$\theta + c$, c	θ,b
Switch to B	0,0	c, $b + c$

Assumption 1 below allows us to focus on the interesting case where coordination benefits are large enough, so that the possibility of coordination failure is a significant strategic consideration. In Remark 2 later, we briefly examine the outcome for other parameter values.

Assumption 1. $c > max\{\theta_H, b\}$.

We need some notations:

Agent A's strategy in the revelation stage, i.e. stage 1, is a mapping α^I from her type space to the space of random messages over M, i.e. $\alpha^I : [\theta_l, \theta_h] \to \Delta(M)$.
We then define the strategies of the agents A and B in stage 2, i.e. the coordination stage:

- Agent A's strategy in the coordination stage is a mapping α^C from A's type, as well as her decision in stage 1, to a probability distribution over the action space $\{adopt\ A, switch\ to\ B\}$, i.e. $\alpha^C : [\theta_l, \theta_h] \times [\theta_l, \theta_h] \to [0, 1]$.
- Following a history where, in stage 1, agent A revealed her type to be θ, let $q_R(\theta)$ denote a mixed strategy of agent B where she plays "Adopt B" with probability $q_R(\theta)$.
- Similarly, following a history where agent A played "Not Reveal θ" in stage 1, q_{NR} denotes a mixed strategy of agent B where she plays "Adopt B" with probability q_{NR}.

Off-the-equilibrium, agent B's belief puts probability 1 on agent A being of a particular type $\theta \in [\theta_l, \theta_h]$.
Finally, agent A's strategy in stage 2, i.e. α^C, is said to be a *cut-off strategy* iff there is some $\hat{\theta} \in [\theta_l, \theta_h]$ such that she adopts A iff $\theta \geq \hat{\theta}$.

Given these notations,the perfect Bayesian equilibria of this game can be defined in a routine fashion.

3. The Analysis

We next solve for the perfect Bayesian equilibria of this game. The focus is on understanding whether, in equilibrium, there will be information revelation or not. As we shall later argue, the underlying strategic uncertainty regarding coordination failure plays a central role in the analysis. For

[3] The coordination continuation game follows [12].

most of the analysis we shall therefore examine equilibria where agent B plays a completely mixed strategy in the coordination stage, thus allowing for the possibility of coordination failure.[4]

This focus on mixed strategy equilibria is in line with many papers investigating coordination problems, e.g. [27] on corporate take-overs, [28] on repeated coordination games, as well as [29] on international environment agreements for addressing greenhouse gas emissions (modelled as a participation game). [29] for example defend their investigation of mixed strategy equilibria on the grounds that it captures the uncertainty of countries in coordinating an effective climate change treaty. In the context of the present model, with strategic uncertainty and multiple Pareto-ranked pure strategy equilibria, any pure strategy equilibrium selects an equilibrium by fiat (as mentioned by [12] in the context of technology standardization), and thus ignores uncertainty over coordination.

We thus begin with the following definition.

Definition 1. A *PBEM* denotes a perfect Bayesian equilibrium where agent B plays a completely mixed strategy in the coordination stage, i.e. stage 2.

We begin by examining equilibria in the coordination stage. We first examine agent A's strategy following non-revelation of her type by agent A.

Lemma 2. *Consider the stage 2 continuation game where agent A does not reveal her type in stage 1. In any PBEM, agent A plays a cut-off strategy in stage 2.*

Proof. Consider the stage 2 subgame following non-revelation of her type by agent A in stage 1. Consider a PBEM where, in stage 2, agent B plays adopt B with probability q_{NR}, $0 < q_{NR} < 1$.

Next note that the payoff to agent A in this subgame from adopting A, call it π_A(Not Reveal and Adopt A), is increasing in her type θ. Thus

$$\pi_A\,(\text{Not Reveal and Adopt A}) = (1 - q_{NR})c + \theta. \tag{1}$$

Similarly,

$$\pi_A(\text{Not Reveal and Switch to B}) = \mathrm{q_{NR}c}. \tag{2}$$

Let $\hat{\theta}$ be the minimum of all $\theta \in [\theta_l, \theta_h]$ such that π_A(Not Reveal and Adopt A) $\leq$ ß$_{\mathrm{A}}$(Not Reveal and Switch to B). Hence, for all types $\theta \geq (<)\hat{\theta}$, it is optimal to adopt A (switch to B) following non-revelation, given that $0 < q_{NR} < 1$. □

In Lemma 2 below we then consider the equilibrium outcome in the stage 2 subgame following revelation of her type by agent A in stage 1. Given that we have a standard battle of the sexes game, we omit the proof (which is routine).

Lemma 3. *Consider any candidate PBEM such that agent A reveals her type θ in stage 1. In stage 2, agent B plays "Adopt B" with probability $q_R(\theta) = \frac{\theta+c}{2c}$, and has a payoff of $\frac{b+c}{2}$, whereas agent A of type θ plays "Adopt A" with probability $\frac{b+c}{2c}$ and has a payoff of $\frac{\theta+c}{2}$.*

From Lemma 2 note that $q_R(\theta)$ is increasing in θ, so that agent B becomes more aggressive in adopting her own idea as θ increases. This follows from the intuition of mixed strategies itself, which requires the choice of $q_R(\theta)$ to be such that A is indifferent between her two pure strategies.

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[4] For completeness however, we shall later briefly allow for equilibria that involve pure strategies in stage 2 and examine how this affects the non-revelation result. Further, in Section 4, we shall provide a purification argument that provides a foundation for the mixed strategic equilibrium that we examine here.

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This suggests that if an agent A with high θ reveals her type, agent B will respond much more aggressively compared to the case when agent A does not (since in this case agent B's response will be based on the expected average value of θ). This intuition has important implications for the coordination possibilities in the second stage game, and, as we shall find, plays an important role in Proposition 1 (to follow).

Proposition 1 is the central result of this section, showing that in the presence of coordination issues there is no information revelation by agent A (except possibly by a single type). This result not only provides a new insight as to why 'unraveling' may not occur, further, as argued later, this is consistent with some of the anecdotal literature, e.g. on information sharing in committees in network industries.

Proposition 4. *Consider any PBEM. In stage 1, all types of agent A, with the possible exception of one type, strictly prefer non-revelation to revelation.*

Proof. Recall from Lemma 2 that in the event an agent A of type θ reveals her type in stage 1, then her payoff in any PBEM is $\frac{\theta+c}{2}$.

Next suppose that agent A does not reveal her type. Then agent A's payoff in stage 2 is $\theta + c - q_{NR}c$ if she adopts A in stage 2, and $q_{NR}c$ if she switches to B in stage 2. Consequently if agent A of type θ reveals, we must have

$$\frac{\theta + c}{2} \geq q_{nr}c. \tag{3}$$

If the inequality in (3) is strict, then we have, rearranging terms, that

$$\frac{\theta + c}{2} < \theta + c - q_{nr}c. \tag{4}$$

Equation (4) however implies that agent A of type θ will be strictly better off by not revealing and choosing to adopt. Thus, for agent A of type θ to reveal, it is necessary that

$$\frac{\theta + c}{2} = q_{NR}c. \tag{5}$$

But, given that q_{NR} is independent of θ, equation (5) can only hold for at most one value of θ. □

The intuition for non-revelation has to do with coordination possibilities in the second stage game. As argued earlier, for an agent A with a high realization of θ, non-revelation followed by choosing to adopt A is optimal. This follows as revelation would lead the other agent to follow extremely aggressive strategies.

Whereas if θ is low, then agent A's private benefit from adopting A itself is low compared to the possible coordination benefits from c. Consequently agent A is more interested in coordination itself, rather than the identity of the idea on which coordination takes place. Further given that b is large relative to θ, agent B will put a relatively 'large' probability on adopting B in case of information revelation, even if the revealed θ turns out to be small. Therefore agent A has little to gain by revealing information so as to encourage coordination on A. She would rather ensure that coordination takes place on B, since while she loses because agent B's idea is selected, she more than makes up for it because the probability associated with coordination on B is larger.

Note here that we have assumed that off-the-equilibrium path beliefs are passive. The result can easily be extended to show that for all off-the-equilibrium path beliefs of player 2, and for all continuation equilibria, at least one type of player 1 strictly benefits by deviating from full equilibrium.

Interestingly, this non-revelation result appears to be consistent with anecdotal evidence on information sharing within standard-setting committees in network industries. For example, consider participation in patent pools associated with formal standard setting organizations (SSO), with such pools often involving information disclosure. In this context [30] notes that firms often choose not to

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participate in such pools.[5] In particular in their Table 1, [31] find that most pools involve only one-third of the total firms associated with the standard. Additionally, patents included in the pool represent a small fraction of the total patents declared to the related standard, ranging from 10 per cent (the WCDMA pool) to about 89 per cent (the MPEG-4 pool). Thus, voluntary disclosure of information does not appear to be common for standard setting through SSOs in network industries.

We then characterize the equilibrium, showing that there is a 'unique' PBEM.[6]

Proposition 5. *A unique PBEM exists. In this equilibrium there is no information revelation in Stage 1. In Stage 2:*

(i) Agent A adopts her own idea, i.e. A, if and only if $\theta \geq \hat{\theta}$, *where* $\hat{\theta} = F^{-1}(\frac{c-b}{2c})$ *and* $\theta_l < \hat{\theta} < \theta_h$, *and switches to B otherwise,*

(ii) Agent B adopts her own idea, i.e. B, with probability $\frac{1}{2} + \frac{F^{-1}(\frac{c-b}{2c})}{2c}$.

(iii) In this PBEM a type θ *agent A has an expected payoff of:*

$$\pi_A(\theta) = \begin{cases} \theta + \frac{c-\hat{\theta}}{2}, & \text{if } \theta > \hat{\theta}, \\ \frac{c+\hat{\theta}}{2}, & \text{otherwise,} \end{cases}$$

and agent B has an expected payoff of $\frac{b+c}{2}$

Proof. From Proposition 1, we know that with probability 1 there will be no revelation in the first stage.

Next consider stage 2. Given Lemma 1, we know that agent A will be playing a simple cutoff strategy where she adopts A if and only if her type is larger than some cutoff value, call it $\hat{\theta}$. The value of this cutoff $\hat{\theta}$, given that agent B is playing a completely mixed strategy, must make agent B indifferent between adopting B and switching to A, so that

$$(1 - F(\hat{\theta}))c = (1 - F(\hat{\theta}))b + F(\hat{\theta})(b + c) = b + F(\hat{\theta})c. \tag{6}$$

This yields $\hat{\theta} = F^{-1}(\frac{c-b}{2c})$, where $\hat{\theta}$ is well defined since $0 < \frac{c-b}{2c} < 1$ (given that $c > b$). Furthermore, given that agent B adopts B with probability q_{NR}, the cut-off strategy of agent A in the coordination stage will be optimal if, at $\hat{\theta}$, we get the following expression for q_{nr}:

$$\frac{\hat{\theta} + c}{2c} = q_{nr}. \tag{7}$$

Given that $\hat{\theta} = F^{-1}(\frac{c-b}{2c})$, the result follows. □

Figure 1 provides a graphical representation of agent A's payoffs under the three strategic options, not revealing her information, revealing her information and then play "Adopt A", and revealing her information and then play "Switch to B." In order to buttress the claim that it is the possibility of coordination failure that generates the non-revelation result, we then examine two scenarios where there is no coordination failure. As we shall find, information revelation is possible in such cases.

We first consider the case where the agents play a pure strategy equilibrium in stage 2, i.e. depending on θ they coordinate on either A, or B, in the second stage. Consider strategies such that in stage 1, agent A reveals her type irrespective of θ. Further, in case of non-revelation, let the belief of agent B

[5] Firms can decide whether or not to join the patent pool for accessing privately patented information required for developing the standard through the offices of the SSO. Patents can be directly submitted to the SSO (mandatory disclosure required by some SSOs), bypassing the patent pool.

[6] In fact, we can prove that the non-revelation result is unique in the class of revelation strategies, where A reveals its type over finite unions of disjoint sets of the type space. The proof is in Appendix 2.

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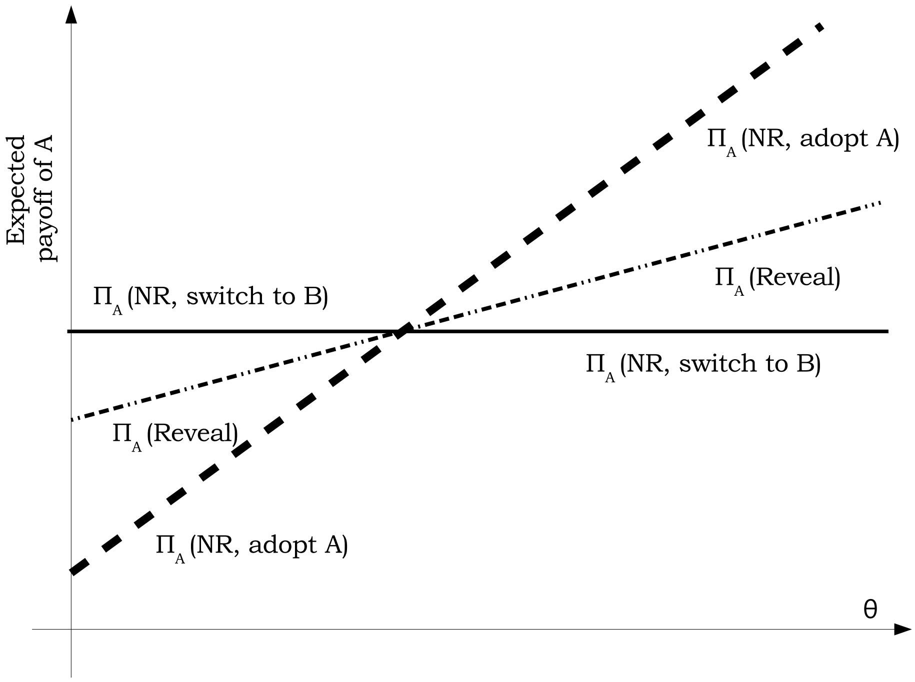

Figure 1. Expected payoff for A with information revelation dominated by non-revelation payoffs

be that agent A is of type θ_h. In stage 2, the agents coordinate on A if $\theta \geq \theta'$, and on B if $\theta < \theta'$, where $\theta' \in (\theta_l, \theta_h)$ is exogenously given. It is straightforward to check that these strategies constitute a perfect Bayesian equilibrium. Note that the equilibrium involves complete information revelation, thus corroborating our central intuition that non-revelation is intimately tied to the possibility of coordination failure[7]. A distinct feature of this coordination game is that not only are the pure strategy equilibria strict, they are also not dominance solvable. As all values of θ and b are greater than zero and less than c in our game, there does not exist regions where one of the two strategies (adopt or switch) strictly dominates the other. Hence, we cannot use the method of global games for selecting any one of the pure strategy equilibria over the other. Full disclosure can also happen in case the agents play a correlated equilibrium in the coordination subgame. In the Appendix, we argue that some correlated equilibria with full disclosure can indeed be sustained as an equilibrium.

Remark 1. We find that the non-revelation results in Propositions 1-2, together with the preceding results on revelation, jointly suggest that it is the presence, or absence of strategic uncertainty that determines whether there is information non-revelation or not. Thus both the non-revelation, as well as the revelation results are of interest. Even so, in future work we plan to examine if one can use some selection mechanism to isolate the non-revelation equilibrium. One strand of the literature on equilibrium selection considers global games and the role of higher order beliefs. The global games framework, as proposed by [32], has been extensively used to study, among others, equilibrium selection in coordination games arising in the pricing of debt ([33]), and to problems of stochastic common learning ([34]). In

[7] Of course there exist equilibria where the agents coordinate on either A or B in stage 2, but there is no information revelation in the first stage.

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this context, [35] examines the role of higher order beliefs and the precision of signals about private vs. public information in equilibrium selection.

Remark 2. We next examine scenarios where the parameter values do not satisfy Assumption 1. Note that if $b > c$, then adopting B is a dominant strategy for agent B. Similarly, if $c < \theta_l$, then adopting A is a dominant strategy for agent A. In either of these cases, the coordination problem disappears, and agent A's payoff is the same irrespective of whether she reveals her own type in stage 1, or not. Thus the interesting case is if $b < c$ and $\theta_l < c < \theta_h$. In this case there is an equilibrium with partial information revelation. Let $\tilde{F}(\theta)$ denote the probability distribution derived from $F(\theta)$ conditional on θ being less than c. It is now straightforward to construct an equilibrium where all A agents with $\theta \geq c$ reveal their type, and choose A in the coordination stage, whereas the other A agents do not reveal their type. In particular, we can mimic the argument in Propositions 1-2 (replacing $F(\theta)$ with $\tilde{F}(\theta)$), to construct equilibrium strategies for all A agents with $\theta < c$. Interestingly, as discussed earlier in the introduction, [9] also demonstrates the existence of equilibrium with partial disclosure in the presence of hard information.

3.1. Efficiency under PBEM

Turning to the efficiency aspects, we say that a perfect Bayesian equilibrium is efficient if the outcome involves both agents choosing A when $\theta \geq b$, and both agents choosing B otherwise.

Proposition 6. *The PBEM discussed in Propositions 1 and 2 is inefficient.*

Proof. Since agent B plays a completely mixed strategy, there is a positive probability that agent B will choose B even when $\theta \geq b$, as well as choose A even when $\theta < b$. □

Remark 3. Note that there exist equilibria that are both efficient, as well as involve complete information revelation in the first stage. In consonance with our theme, however, these involve no strategic uncertainty in coordination. Consider strategies where in stage 2, both the agents coordinate on A if $\theta \geq b$, and on B otherwise. Further, following non-revelation by agent A, let agent B's belief be that A is of type θ_h. Then the outcome where agent A reveals her type in stage 1 can be sustained as an equilibrium. Further, coordination on A happens iff $\theta \geq b$, so that the outcome is efficient.

4. Purification of agent B's mixed strategies

The non-revelation result in Propositions 1 and 2 are open to the critique that we examine equilibria where agent B plays a completely mixed strategy whenever A reveals her private information about her own type. In an effort to address this issue, we next argue that there exists some natural extension of our framework such that sustaining the non-revelation result does not require the B agent to play mixed strategies in the coordination stage.

To this end, we extend the baseline framework to allow for a unit mass of B-agents with different realizations over their private benefit b, where the exact realization of b for any given B agent is private information. We then argue that a version of Harsanyi's purification theorem goes through, in that, following type revelation by the A agent, the continuation pure strategy equilibrium played by the B-type agents generates the same probability distribution as the mixed strategy equilibrium in the baseline model (see Lemma 3 later). We next use this result to demonstrate (in Proposition 4 later on), that the non-revelation results goes through under this re-formulation. Formally, the B agents' private benefit from adopting B is distributed over the compact, continuous type space Ξ, where $\Xi = [b_l, b_h] \subset \mathbb{R}_+$, with distribution $G(b)$, where $b_l < b_h$, and $G(b)$ is non-degenerate and strictly increasing. Further, for this section we assume that an analogue of Assumption 1 goes through, i.e. $c > \max\{\theta_h, b_h\}$.

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We next turn to modelling the coordination benefits in this setup. The coordination benefit on technology i, $i \in \{A, B\}$, arises if and only if the A agent, as well as a positive measure of B-agents adopt this technology. Thus conditional on the A agent adopting technology i, the total coordination benefit from i is given by $c.x$, where x denotes the fraction of B-agents opting for this technology. Thus the payoff matrix in this new game is given by:

Table 2. Modified payoff matrix for the one-shot game

	Switch	Adopt B
Adopt A	$\theta + c(1-l)$, $c(1-l)$	$\theta + c(1-l)$,b
Switch	cl,0	cl, $b + cl$

We next introduce some definitions that we need for the analysis:

Agent A's strategy in stage 1, β^I, maps from her type space Θ to the set of probability distributions over M, i.e. $\Delta(M)$. Hence $\beta^I : \Theta \to \Delta(M)$.
We then define the strategies of the agents in stage 2, i.e. the coordination stage:

- In stage 2, agent A's strategy β_A^C maps from her type space Θ, as well as her message is stage 1, to the set of probability distributions over her action space. Hence $\beta_A^C : \Theta \times M \to [0, 1]$.
- In stage 2, agent B's strategy is a mapping from her own type space Ξ, and the disclosure made by A in stage 1, to the set probability distributions over her own actions. Hence $\beta_B^C : \Xi \times M \to [0, 1]$.
- Agent A's strategy in Stage 2, β_A^C, is said to be a cut-off strategy if there exists $\hat{\theta} \in \Theta$ such that A adopts A iff $\theta \geq \hat{\theta}$.
- Agent B's strategy in Stage 2, β_B^C, is said to be a cut-off strategy if there exists $\hat{b} \in \Xi$ such that B adopts B iff $b \geq \hat{b}$.

Off-the-equilibrium, every b-type B agent's belief puts probability 1 on agent A being of a particular type θ, where $\theta \in [\theta_l, \theta_h]$.

One can define a perfect Bayesian equilibrium of this game in the usual manner.

4.1. Analysis: Non-revelation by the A agent in stage 1

Given the complementarities inherent in this game, cut-off strategies arise naturally for the A, as well as the B agents. In the subgame following type revelation by the A agent, we therefore focus on equilibria where the B agents play a cut-off strategy with a cut-off of $\hat{b}$. Next consider the subgame following non-revelation by agent A. Let $\hat{\theta}_{NR}$ denote the cut-off for the A agent, and $\hat{b}_{NR}$ denote the cut-off for the B agents in the subsequent coordination stage.

Definition 2. *A PBEC for the modified game is a perfect Bayesian equilibrium where, in every subgame, the B agents play cut-off strategies with strictly interior cut-offs in the coordination stage of the game.*

We first argue that in the unique PBEC for the continuation game following type revelation by the A agent, the probability that the B agents adopt B is the same as that under the PBEM equilibrium where agent B plays a completely mixed strategy (see Lemma 1).

Lemma 7. *Consider the stage 2 subgame where agent A reveals her type θ in stage 1.*

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(a) In any PBEC of this subgame, the cut-off for agent B, $\hat{b}(\theta)$, and the probability that agent A adopts A, i.e. $\alpha(\theta)$, solves:

$$\begin{aligned}\hat{b}(\theta) &= (\alpha - \frac{c+\theta}{2c})c,\\ \alpha(\theta) &= \frac{(c+\theta)}{2c} + \frac{G^{-1}((c-\theta)/2c)}{c}.\end{aligned}$$

(b) A θ-type A agent's payoff from revealing her type is $\frac{c+\theta}{2}$.

(c) The equilibrium cut-off for the B-types is unique and interior, i.e. $0 < \hat{b} < 1$. Moreover, it generates the same probability distribution over the two choices, i.e. A and B, as that under the PBEM equilibrium following type revelation by the A agent in the baseline model.

Proof. (a) Consider the subgame following the A agent revealing her type to be θ. In this subgame, let the B agents adopt a cutoff strategy involving a cutoff of $\hat{b}(\theta)$. Thus defining $l(\theta)$ as the fraction of B agents that adopt B, $l(\theta) \equiv 1 - G(\hat{b}(\theta))$. Let $\alpha(\theta)$ be the probability that the A agent adopts A.

First consider the decision problem facing a B agent with private valuation b. Note that the expected payoff for agent B, when she switches to B, is:

$$\pi_B(B) = (1-\alpha).(b+cl) + \alpha.b, \tag{8}$$

whereas her expected payoff when she adopts A, is:

$$\pi_B(A) = \alpha.c(1-l). \tag{9}$$

For the indifferent type $\hat{b}$, equating (8) and (9), we get:

$$\hat{b} = (\alpha - l)c. \tag{10}$$

Next consider the decision problem facing the A agent with private valuation θ. Agent A's expected payoff from adopting A:

$$\pi_A(A) = \theta + c(1-l), \tag{11}$$

whereas agent A's expected payoff from switching to B:

$$\pi_A(B) = c.l. \tag{12}$$

For the A agent of type θ to be indifferent between A and B, from (11) and (12) we find that:

$$l(\theta) = \frac{c+\theta}{2c}. \tag{13}$$

Given that $c > \theta_h \geq \theta$, it is straightforward to check that $0 < l(\theta) < 1$. Therefore, $\hat{b}(\theta) = (\alpha - \frac{c+\theta}{2c})c$.

Solving (10) and (13) simultaneously, we find that:

$$\alpha = l(\theta) + \frac{\hat{b}}{c} = \frac{(c+\theta)}{2c} + \frac{G^{-1}((c-\theta)/2c)}{c} > 0, \tag{14}$$

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using the fact that $l(\theta) = \frac{c+\theta}{2}$ (from (13)), and $G(\hat{b}(\theta)) = 1 - l(\theta) = \frac{c-\theta}{2c}$.[8]

(b) Using (12), the A agent's expected payoff is given by $cl(\theta)$. Next, using (13), we find that $cl(\theta) = \frac{c+\theta}{2}$.

(c) Note that $G(\hat{b}) = 1 - l(\theta) = \frac{c-\theta}{2c}$. Given that $G(b)$ is strictly increasing, $\hat{b}$ is unique. Given that $c > \theta_h \geq \theta$, it is straightforward to check that $0 < G(\hat{b}) < 1$, so that $b_l < \hat{b} < b_h$.

Next observe that the fraction of B agents adopting B, i.e. $l(\theta) = 1 - G(\hat{b}) = \frac{\theta+c}{2c}$ (from (13)). From Lemma 1, recall that $q_R(\theta) = \frac{\theta+c}{2c}$, where $q_R(\theta)$ is the probability with which B adopts B in the our baseline model for the subgame where agent A reveals her type to be θ. Thus $l(\theta) = q_R(\theta)$. □

Proposition 4 below is the central result in this section. We find that in the revelation stage of the modified game, agent A does not reveal her type, showing that the non-revelation result is robust to this modification.

Proposition 8. *Consider any PBEC of the modified game.*

(a) Consider the stage 2 subgame where agent A does not reveal her type in stage 1. In any PBEC, agent A plays a cut-off strategy in stage 2.

(b) In stage 1, all types of agent A, with the possible exception of one type, strictly prefer non-revelation to revelation.

(c) If $F(\theta) + \frac{\theta}{2c} + \frac{G^{-1}((c-\theta)/2c)}{c}$ is monotonic in θ, then this game has a unique PBEC.

Proof. (a) The proof mimics that of Lemma 1 earlier.

(b) Given Proposition 4(a), we restrict attention to PBEC where, following non-revelation the A agent plays a cutoff strategy. Let the cutoffs following non-revelation be $\hat{\theta}_{NR}$ for the A, and $\hat{b}_{NR}$ for the B agents. Equating the payoffs from switching to A and adopting B for the indifferent B agent, i.e. of type $\hat{b}_{NR}$, we have that

$$\hat{b}_{NR} = (G(\hat{b}_{NR}) - F(\hat{\theta}_{NR}))c. \tag{15}$$

Similarly, equating the payoffs from A and B for the indifferent A agent, i.e. of type $\hat{\theta}_{NR}$, we have that

$$G(\hat{b}_{NR}) = \frac{c - \hat{\theta}_{NR}}{2c}. \tag{16}$$

Given that $c > \theta_h \geq \hat{\theta}$, it follows that $0 < G(\hat{b}_{NR}) < 1$, so that $b_l < \hat{b}_{NR} < b_h$.

Next, from (15) and (16), we have that

$$F(\hat{\theta}_{NR}) = \frac{(c - \hat{\theta}_{NR})}{2c} - \frac{G^{-1}((c - \hat{\theta}_{NR})/2c)}{c}. \tag{17}$$

It is straightforward to check that $F(\hat{\theta}_{NR}) < 1$, so that $\hat{\theta}_{NR} < \theta_h$.[9] Given $\hat{\theta}_{NR}$, $\hat{b}_{NR}$ can then be solved using (15). Further, if $\hat{\theta}_{NR} = \theta_l$, then from (15), $\hat{b}_{NR} = cG(\hat{b}_{NR})$. In all cases, for all $\theta \geq \hat{\theta}_{NR}$, A adopts A and for all $\theta < \hat{\theta}_{NR}$, A switches to B upon non-revelation of θ in stage 1.

---

[8] Can one provide sufficient conditions such that $\alpha < 1$? This is equivalent to showing that $\frac{G^{-1}((c-\theta)/2c)}{(c-\theta)/2c} < c$. Clearly, one sufficient condition is that $G(b)$ satisfies both (a) $\frac{G^{-1}(x)}{x}$ be increasing in x, and (b) $\frac{G^{-1}(x)}{x} \leq 1$, $\forall x$. Note that this is satisfied whenever $G(b)$ is uniform.

[9] Can one provide sufficient conditions such that $\hat{\theta}_{NR} > \theta_l$? This is equivalent to showing that $\frac{G^{-1}((c-\hat{\theta}_{NR})/2c)}{(c-\hat{\theta}_{NR})/2c} < c$. Clearly, one sufficient condition is that $G(b)$ satisfies both that (a) $\frac{G^{-1}(x)}{x}$ is increasing in x, and (b) $\frac{G^{-1}(x)}{x} \leq 1$, $\forall x$. Note that this is satisfied whenever $G(b)$ is uniform.

Note that for $\hat{\theta}_{NR} > \theta_l$, the expected payoff for A, denoted $\pi_A(NR)$, is:

$$\pi_A(NR) = \begin{cases} \theta + c.G(\hat{b}_{NR}), \text{ if } \theta \geq \hat{\theta}, \\ c[1 - G(\hat{b}_{NR})], \text{ if } \theta < \hat{\theta}. \end{cases} \quad (18)$$

Whereas if $\hat{\theta}_{NR} = \theta_l$, then from (16) and (18), the expected payoff for A is:

$$\pi_A(NR) = \theta + \frac{c - \theta_l}{2}, \ \forall \ \theta. \quad (19)$$

We first consider $\hat{\theta}_{NR} > \theta_l$:

1. At $\theta = \hat{\theta}_{NR}$, $\pi_A(NR) = \hat{\theta}_{NR} + c.G(\hat{b}_{NR}) = \hat{\theta}_{NR} + c.(\frac{c-\hat{\theta}_{NR}}{2c}) = \frac{\hat{\theta}_{NR}+c}{2} = \pi_A(R)$.
2. For all types of $\theta > \hat{\theta}_{NR}$, $\pi_A(NR) - \pi_A(R) = \frac{\theta}{2} - c[\frac{1}{2} - G(\hat{b}_{NR})]$. Note that $\frac{\partial[\pi_A(NR) - \pi_A(R)]}{\partial \theta_{NR}} = 1/2 > 0$, and at $\theta = \theta_h$, this difference $\pi_A(NR) - \pi_A(R) = \frac{\theta_h}{2} - c[\frac{1}{2} - G(\hat{b}_{NR})]$. This expression is positive, iff $\hat{b}_{NR} > G^{-1}(\frac{c-\theta_h}{2c})$. Finally, from (16), $\hat{b}_{NR} = G^{-1}(\frac{c-\hat{\theta}_{NR}}{2c}) > G^{-1}(\frac{c-\theta_h}{2})$, since $\hat{\theta}_{NR} < \theta_h$ and $G(B)$ is strictly increasing. Next recall that As discussed earlier, $\pi_A(R) = \pi_A(NR)$ at $\theta = \hat{\theta}_{NR}$.Therefore, in the range $(\hat{\theta}_{NR}, \theta_h]$, $\pi_A(R) < \pi_A(NR)$.
3. Next consider θ in the range $[\theta_l, \hat{\theta})$. Over this range $\pi_A(NR)$ is independent of θ, whereas $\pi_A(R)$ is strictly decreasing in θ. Given that $\pi_A(NR)$ equals $\pi_A(R)$ at $\hat{\theta}_{NR}$, it follows that $\pi_A(NR) > \pi_A(R), \forall \theta \in [\theta_l, \hat{\theta}_{NR})$.

Therefore, whenever $\hat{\theta}_{NR} > \theta_l$, A's expected payoff from non-revelation is greater than that from revelation $\forall \theta \in [\theta_l, \theta_h]$, except for $\theta = \hat{\theta}_{NR}$, where these payoffs are equal. Finally consider the case where $\hat{\theta}_{NR} = \theta_l$ in the non-revelation equilibrium. Note that for any $\theta \in \Theta$, $\pi_A(R) = \frac{\theta+c}{2} < \theta + \frac{c-\theta_l}{2} = \pi_A(NR)$. (c) Given that $F(\theta) + \frac{\theta}{2c} + \frac{g^{-1}((c-\theta)/2c)}{c}$ is monotonic in θ, from (17) it follows that $\hat{\theta}_{NR}$ is unique. This in turn ensures that $\hat{b}_{NR}$ is unique. □

5. Extensions

In this section we argue that the non-revelation result is robust to three extensions, viz. both sided asymmetric information, imprecise information disclosure and mandatory disclosure of information.

5.1. Both-sided Asymmetric Information

Consider the case where both the agents have private information about their own types, with agent A's (respectively B's) type being denoted by θ_A (respectively θ_B). For simplicity, let θ_A and θ_B be identically and independently distributed with distribution function $F(\theta)$ (assumed to be strictly monotonic), and support $[\theta_l, \theta_h]$. While agent $i, i \in \{A, B\}$, knows her own type, she only knows the distribution of agent $j \neq i$, i.e. $F(\theta)$. Consider a simple modification of the earlier game whereby, in stage 1, both the agents simultaneously choose an element from $M = [\theta_l, \theta_h] \cup \{\text{Not Reveal } \theta\}$, i.e. whether to reveal, or not.

Let $\pi_i(i = X, j = Y)$ denote the payoff of agent i in case in stage 1 she selects X and agent j selects Y, where $X, Y \in M_i = [\theta_l, \theta_h] \cup \{\text{Not Reveal } \theta_i\}$. We then show that even with both-sided asymmetric information, a version of the earlier no revelation result in Proposition 1 goes through.

Proposition 9. *Consider any perfect Bayesian equilibria where, in stage 2, an agent uses cutoff strategies in case she has not revealed her type, and completely mixed strategies in case she has. In any such equilibrium, all θ types lower than a cutoff $\hat{\theta}$ are indifferent between revealing and not revealing her type. All types higher than this cutoff type prefer not to reveal. Thus there exists a PBEM where there is no information revelation.*

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Proof. *Step (i).* We first prove that in case agent j reveals her type, at most one type of agent i, $i \neq j$, will reveal her type. We know from our earlier results that if both the agents reveal their types, then the expected payoff for agent i in the completely mixed strategy equilibrium is $\frac{\theta_i+c}{2c}$.

Suppose that agent i decides not to reveal her type, given that j has revealed her type. Clearly, the mixed strategy equilibrium in the second stage game is identical to that under the unique PBEM characterized in Propositions 1 and 2. Thus the payoff of agent i is:

$$\pi_i(i = \text{Not reveal } \theta_i | j = \text{Reveal } \theta_j) = \begin{cases} \theta_i + (1 - \frac{c+\hat{\theta}}{2c})c, \text{ if } \theta_i > \hat{\theta}, \\ \frac{c+\hat{\theta}}{2c}c, \text{ otherwise.} \end{cases}$$

The difference between the expected equilibrium payoff to i from not revealing and revealing, given that j reveals, is strictly positive for all values of θ as shown below:

$$\begin{aligned} \pi_i(i = \text{Not Reveal } \theta_i | j = \text{Reveal } \theta_j) \quad - \quad & \pi_i(i = \text{Reveal } \theta_i | j = \text{Reveal } \theta_j) = \\ & \begin{cases} \frac{\theta_i - \hat{\theta}}{2} > 0, \text{ if } \theta_i > \hat{\theta}, \\ \frac{\hat{\theta} - \theta_i}{2} > 0, \text{ otherwise.} \end{cases} \end{aligned}$$

Given that j reveals, i would therefore prefer to not reveal and adopt for $\theta_i > \hat{\theta}$ and not reveal and switch for $\theta < \hat{\theta}$. Only the type $\hat{\theta}$ is indifferent.

Step (ii) We then argue that in case agent j does not reveal her type, all types lower than $\hat{\theta}$ are indifferent between revelation and non-revelation, whereas all types higher than this cutoff strictly prefer non-revelation to revelation.

In this case, if agent i does not reveal, the coordination cutoff $\hat{\theta}$ ensures that she is indifferent between adopting and switching, so that

$$\hat{\theta} + F(\hat{\theta})c = (1 - F(\hat{\theta}))c. \tag{20}$$

As $F(\theta)$ is strictly monotonic, $\hat{\theta}$ exists in the interior of the type space and is unique. The expected payoff of agent i from not revealing, given that j has not revealed her type is:

$$\pi_i(i = \text{Not Reveal } \theta_i | j = \text{Not Reveal } \theta_j) = \begin{cases} \theta_i + \frac{c-\hat{\theta}}{2}, \text{ if } \theta_i > \hat{\theta}, \\ \frac{c+\hat{\theta}}{2}, \text{ otherwise} \end{cases}$$

where $F(\hat{\theta}) = \frac{c-\hat{\theta}}{2c}$.

Now consider the case where agent i reveals her information, given that j does not. From our earlier analysis of one-sided asymmetric information case, the expected mixed strategy payoff for agent i is $\frac{c+\hat{\theta}}{2}$.

Hence, we have:

$$\begin{aligned} & \pi_i(i = \text{Not Reveal } \theta_i | j = \text{Not Reveal } \theta_j) - \pi_i(i = \text{Reveal } \theta_i | j = \text{Not Reveal } \theta_j) \\ = & \begin{cases} \theta_i - \hat{\theta} > 0, \text{ if } \theta_i > \hat{\theta}, \\ 0, \text{ otherwise.} \end{cases} \end{aligned}$$

Thus all types with $\theta \leq \hat{\theta}$ are indifferent about revealing or not revealing, if j does not reveal. All types strictly greater than $\hat{\theta}$ prefer non-revelation to revelation.

Finally, taking steps (i) and (ii) together, the proposition follows.[10] □

[10] It is straightforward to show that there exists an equilibrium where neither agent reveals in stage 1, and, in stage 2, switches if and only if $\theta_i \leq \hat{\theta}$.

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Remark 4. The characterization of this equilibrium, in terms of $\hat{\theta}$, is as follows: In Stage 1, there is no information revelation. In Stage 2: agent i adopts her own idea, θ_i, if and only if $\theta_i \geq \hat{\theta}$, where $\hat{\theta} = F^{-1}(\frac{c-\hat{\theta}}{2c})$ and $\theta_l < \hat{\theta} < \theta_h$, and switches to the other agent's idea otherwise.

5.2. Imprecise Information Revelation

Note that the informed agent can either reveal her own type truthfully, or can refuse to reveal. This message space does not allow for imprecise disclosures, unlike e.g. [11] who not only allow for imprecise revelation, but also cheap talk.

Given that strategic uncertainty in coordination is at the heart of this paper, in this sub-section we allow for imprecise information revelation though in the presence of strategic uncertainty, showing that the non-revelation equilibrium does survive.

Consider a scenario where agent A is allowed to report that her type lies within a set, rather than the exact value. Information is still assumed to be hard however, so that agent A can only make truthful claims[11]. For technical reasons we restrict attention to disclosures within closed sets only. In stage 1, agent A chooses an element from $\overline{\Theta}$, where $\overline{\Theta}$ is the set of all closed subsets of $[\theta_l, \theta_h]$. However information is hard in the sense that if an agent of type θ chooses $\Theta(\theta) \in \overline{\Theta}$ in stage 1, then it must be the case that $\theta \in \Theta(\theta)$. Note that since $[\theta_l, \theta_h] \in \overline{\Theta}$, revealing no information is also an option.

Consider the PBEM of the baseline model described in Propositions 1 and 2. Define q^*_{NR} (respectively $q^*_R(\theta)$) to be the probability that agent B adopts B in the second stage, given that agent A chooses not to reveal any information (respectively reveals her type θ). Recall that

$$q^*_{NR} = \frac{1}{2} + \frac{F^{-1}(\frac{c-b}{2c})}{2c}, \text{ and } q^*_R(\theta) = \frac{1}{2} + \frac{\theta}{2c}.$$

Further, (a) $q^*_{NR} > q^*_R(\theta)$ if and only if $\theta < \hat{\theta}$, and (b) $q^*_R(\theta)$ intersects q^*_{NR} from below at the coordination cutoff point $\hat{\theta}$.

We then prove that there exists an equilibrium where there is no information revelation by agent A.

Proposition 10. *There exists an equilibrium where there is no information revelation by agent A in stage 1 (except possibly by a single type).*

Proof. The argument is by construction. Consider the following strategies:

In stage 1, agent A reveals no information. In case agent A selects any other $\Theta' \in \bar{\Theta}$ instead, then agent B believes that A's type is $\sup \Theta'$.

In stage 2, the agents play a completely mixed strategy equilibrium where agent B's beliefs are as described above.

It remains to check if any type A agent has an incentive to deviate and reveal her type in stage 1. Suppose an agent of type θ' deviates and chooses $\Theta' \in \overline{\theta}$, where $\theta' \in \Theta'$. Let $\theta'' = \sup\ \Theta'$. Recall that agent A's payoff from selecting Θ', is $\theta' + c - q^*_R(\theta'')c$, where $q^*_R(\theta'') = \frac{1}{2} + \frac{\theta''}{2c}$. Given agent B's belief, and the fact that agent A's payoff is decreasing in $q^*_R(\theta)$, agent A cannot do any better than to announce θ' itself (more generally announce a set with θ' as its supremeum). But if $\theta' > \hat{\theta}$, then agent A would prefer not to reveal and adopt, rather than reveal, since $(\theta' + c) - q^*_{NR}c > (\theta' + c) - q^*_R(\theta')c$. This is because $q^*_{NR} < q^*_R(\theta)$ for all $\theta > \hat{\theta}$. If $\theta' < \hat{\theta}$, then type θ' would prefer not to reveal and switch, getting a payoff of $q^*_{NR}c$, as opposed to $q^*_R(\theta)c$ if she revealed her type, since $q_{NR^*} > q^*_R(\theta)$ for all $\theta < \hat{\theta}$. □

[11] Such imprecise revelation may be attractive in scenarios where the technologies may possibly be copied if revealed. Note however that while we model the possibility of imprecise information revelation, it is not assumed to yield any gain in utility.

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5.3. Mandatory Disclosure: Coordination in Standards Committee

We now compare the coordination probability under the PBEM vis-a-vis that under mandatory information revelation followed by a completely mixed strategy. This issue has policy relevance for standards committees that are interested in fostering coordination, the question being whether mandatory disclosure necessarily increases coordination probabilities in the presence of strategic uncertainty in coordination. Effective coordination increases the reputation of a standardization organization such as the IEEE as an impartial arbiter in the standards process and indirectly increases its payoffs.[12] These organizations highlight the number of successful standards recorded through their offices in detail.

Fixing θ, let $\psi_R(\theta)$ denote the coordination probability on either one of the two technologies, either A or B, under mandatory disclosure (full revelation) followed by mixed strategies in the coordination phase. Similarly, let ϕ_{NR} denote the coordination probabilities under the unique PBEM. With complete revelation, the coordination probability in the completely mixed strategy equilibrium

$$_R(\theta) = (1 - p_R)q_R + (1 - q_R)p_R = \frac{c^2 - b\theta}{2c^2}, \tag{21}$$

where p_R and q_R are the probabilities with which agents A and B adopt their own ideas respectively, $0 < p_R, q_R < 1$. Whereas the coordination probability under the unique PBEM

$$_{NR} = (1 - F(\hat{\theta}))(1 - q_{NR}) + F(\hat{\theta})q_{NR} = \frac{c^2 - b\hat{\theta}}{2c^2}, \tag{22}$$

where recall that q_{NR} is the probability with which B adopts and A plays a simple cutoff strategy at $\hat{\theta}$. Thus, the difference in expected probability of coordination:

$$\int_{\theta_l}^{\theta_h} \psi d(F(\theta)) = \int_{\theta_l}^{\theta_h} [\psi_R(\theta) - \psi_{NR}] d(F(\theta)) = \frac{b}{2c^2}(\bar{\theta} - \hat{\theta}), \tag{23}$$

where $\bar{\theta}$ is the average value of θ.

Proposition 11. *The overall expected coordination probability through mandatory information disclosure is greater than or equal to that with the non-revelation equilibrium iff* $\bar{\theta} \geq \hat{\theta}$.

It is interesting to note, therefore, that mandatory disclosure need not improve coordination probability in the game. This follows directly from the fact that revelation makes the opponent more aggressive. Recall that $q_R(\theta)$ is increasing in θ, whereas q_{NR} is independent of θ. For all types θ higher than $\hat{\theta}$, q_{NR} is greater than $q_R(\theta)$, consequently agent B is more aggressive without mandated disclosure than with mandated disclosure. For all types lower than $\hat{\theta}$, agent B is less aggressive without mandated disclosure and the converse holds.

Example. If θ is uniformly distributed over $[0, 1]$, $c = 2$ and $b = 1$, with $\hat{\theta} = \frac{c-b}{2c} = \frac{1}{4}$ and $\bar{\theta} = \frac{1}{2}$, $\int_{\theta_l}^{\theta_h} \psi d(F(\theta)) = \frac{1}{4} > 0$ leading to lower overall expected coordination probability with mandated disclosure in comparison with the no disclosure equilibrium. On the other hand, if the support of the distribution changes to $[0, \frac{1}{2}]$, mandated disclosure and no disclosure equilibria achieve the same expected probability of coordination, as $\bar{\theta} = \hat{\theta} = \frac{1}{4}$. If we change the support of the distribution to

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[12] Many, but not all, patent pools linked to standard setting organizations have mandatory disclosure rules as noted in [36], [37].

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$[0, \frac{1}{4}]$, expected coordination probability is higher with mandated disclosure than no disclosure, as the mean of the distribution falls to $\frac{1}{8} < \hat{\theta}$.

6. Application

The benchmark model with one-sided asymmetric information analyzed in this paper finds applications in many economic environments. In this section, we highlight one such example.

6.1. Standardization in Network Industries

Consider technology standardization in a network industry. In these industries, e.g. telecommunication, computer software, hardware and gaming devices, coordination among incompatible technologies is a key component for success.[13] In such cases consumers mostly purchase unitary amounts of the relevant products that use some particular technology standard. Consequently, consumers are locked into that particular technology and would be left stranded in case this technology is superseded by a competing one. Fearing this, the consumers may be unwilling to purchase the good at all until a standard emerges. Hence, compatibility/standardization among incompatible technologies is central to developing and expanding such markets. Of course, splintering and inertia are important features of technology adoption in this context ([38]).

In our framework such benefits are captured via the parameter c, i.e. the exogenous benefit from coordination. At the same time agents have vested interests in selecting their own technology (i.e. "idea"). This gives rise to the private benefits θ and b for the two agents.[14]

Note that the game form adopted in this paper has a natural interpretation in this context, that of standardization via committees. Such committees are actually a commonly used coordinating device in such industries. The GSM (Group Sociale Mobile) standard, for example, was developed by a very large committee (involving 14 EU countries, handset providers, chip manufacturers and service providers), which deliberated over the features of the standard. The third generation UMTS protocol, the successor to GSM, was developed by the Electronics Communications Committee of the CEPT. At present GSM and its successors are deployed in 82 percent of mobile phone networks worldwide.[15] In telecommunications standards were commonly developed through official standards bodies, such as the ITU.

Further, our assumption of one-sided asymmetric information seems an appropriate one in this context. This is because as in most technology driven fields, in network industries also there are only a finite number of new ideas that emanate from research and development, and it is rare that many participants in a coordination game have private information regarding the technology.[16]

Finally our central result, i.e. the possibility of non-revelation, is consistent with anecdotal evidence on information sharing in standard-setting committees in network industries, such as the development

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[13] The GSM (Group Sociale Mobile) *standard* in mobile technology was a key element behind the phenomenal success of mobile telephony. For example, the mobile sector in India has grown from around 10 million subscribers in 2002, to over 684 million subscribers around 2016 (www.statista.com). Similarly the e-mail owes a lot of its popularity to the successful *SMTP* (Simple Mail Transfer Protocol). Historically as well, evolution of standards has played an important role in many areas. To name a few, the development of the metric system, standardization of railroad gauges, the development of standardized equipment and organisms for laboratory experiments, all played prominent roles at various points of history.

[14] Such conflict of interest have led to well known standard wars, e.g. Betamax versus VHS in videocassette recorders in the 1980s, QWERTY versus DVORAK in typewriting keyboards, Schick versus Gillette among razor blades, etc.

[15] GSM was established in 1987 with nearly 800 of the world's mobile operators as well as more than 200 companies in the broader mobile ecosystem, including handset makers, internet providers, etc. Committees are of course not universal. For example, the SMTP protocol in e-mail was a market driven one.

[16] As one example among many, consider a GSM (Groupe Sociale Mobile) meeting for increasing the throughput of data over GPRS system in mobile phones. Here Ericsson proposed Enhanced Data Rates over GSM Evolution (EDGE). While other committee members were aware of this idea, Ericsson shared private information that only it had. Refer to: http://www.ericsson.com/res/docs/whitepapers/evolution_to_edge.pdf.

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of the international MPEG-2 standard (ISO/IEC 13818) for broadcasting digital television signals by terrestrial, cable, and direct broadcast satellite TV systems was developed by the Moving Pictures Expert Group (MPEG).[17] As mentioned earlier, our result is consistent with [31] who establishes limited voluntary revelation of private information through patent pools linked to standard setting through SSOs. [40] also establishes non-participation in patent pools for R& D agents for the standard setting process, given equal sharing of licence fees from patents. In this context our analysis suggests that the potential benefit from committee-driven standards need not be information transfer, even if it is allowed for. Interestingly, it is the very uncertainty over coordination that may lead to non-revelation of information.

7. Conclusion

We demonstrate non-revelation of private information in an asymmetric information Battle-of-the-Sexes game with one-sided asymmetric information. The result holds despite information revelation being costless, and for a large class of disclosure rules, as long as there is truthful reporting. This result is robust to several extensions, including both-sided asymmetric information. Thus our results unearth a link between strategic uncertainty in coordination and information (non-)revelation, which is new in the literature. Further, in the context of standardization in network industries, the non-revelation result suggests that information revelation is unlikely to result from standardization committees. This, in turn, suggests avenues for further research in terms of optimal design of mandatory disclosure rules, and patent pools. We also plan to extend the basic model to address problems of commitment and externalities such as coordination benefits correlated with private benefits.

[17] [39] notes that some hours prior to the formation of the MPEG-2 patent pool for forming this standard, Lucent opted out of the pool. This is evidence of a agent choosing not to share her private information for standard formation.

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Appendix 1: Correlated Equilibrium

We demonstrate that there is full revelation of private information in the correlated equilibrium of the one-shot game discussed in section 2. This bolsters our intuition that non-revelation is driven by uncertainty in coordination. Had there been an impartial third party acting as a correlating device, there would have been complete information revelation in our one-shot game.

Suppose that following complete information revelation in Stage 1, a third party tosses an unbiased coin at the beginning of Stage 2. In case of Heads, the third part instructs each agent to select technology A, and to play B otherwise. Consider strategies whereby in Stage 1, agent A reveals her type for all θ. Subsequently in Stage 2, both agents follow the recommendations made by the third party. Whereas in case of no information revelation, the agents play the completely mixed strategy Stage 2 equilibrium.

In the equilibrium following information revelation, agent A gets $[\frac{(\theta+c)}{2} + \frac{c}{2}] = c + \frac{\theta}{2}$ while agent B gets $[\frac{(b+c)}{2} + \frac{c}{2}] = c + \frac{b}{2}$. This payoff for agent A is strictly greater than the non-revelation payoff from Stage 2, as $c > \theta$.

$$\pi_A(\text{correlated}) - \pi_A(NR) = \begin{cases} c + \frac{\theta}{2} - [\theta + \frac{c-\hat{\theta}}{2}] > 0, \text{ if } \theta > \hat{\theta}, \\ c + \frac{\theta}{2} - [\frac{c+\hat{\theta}}{2}] > 0, \text{ otherwise.} \end{cases}$$

Note that any correlated equilibrium which randomizes among the strict pure strategy equilibria (A,A) and (B,B) with a probability greater than or equal to $\frac{1}{2}$ on (A,A) will be consistent with full disclosure in stage 1, as this will give agent A an expected payoff greater than the non-revelation payoff.

Appendix 2: Uniqueness of the non-revletion PBEM over a larger class of disclosure strategies

We now establish that no information revelation is unique in the class of disclosure strategies, where A reveals its type over finite unions of disjoint sets of A's type space. This is a very large class of disclosure strategies, over which we show non-revelation to hold uniquely in equilibrium.

Consider the possible disclosure set of A to be R, where R is either a continuous interval or a finite union of disjoint intervals. Therefore,

$$R = \cup_{s=1}^{n} [\theta'_s, \theta''_s].$$

Let R^c be the set (either an interval or a finite union of disjoint intervals in the type space Θ) over which no type of firm A reveal their type. Note that $\hat{\theta}$ is the cut-off type of A in R^c which is indifferent between adopting A and switching to B.

Lemma 12. *The completely mixed strategy of firm B, q_R (if firm A reveals) or q_{nr} (if firm A does not reveal) obeys a single crossing property in the type space of firm A, so that $q_{nr} > q_R \ \forall \ \theta < \hat{\theta}$ and $q_{nr} < q_R \ \forall \ \theta > \hat{\theta}$.*

1. *$0 < q_{nr} < 1$ is constant. q_R increases linearly with θ.*
2. *q_R intersects q_{nr} from below at the coordination cutoff point $\hat{\theta}$.*
3. *q_{nr} increases linearly in $\hat{\theta}$.*

Proof.
1. The proof follows from equations the fact that $q_{nr} = \frac{\hat{\theta}+c}{2c}$ whereas $q_R = \frac{\theta+c}{2c}$, as discussed in the PBEM of the one-shot game.
2. Note that $q_{nr} = \frac{1}{2} + \frac{\hat{\theta}}{2c}$ and $q_R = \frac{1}{2} + \frac{\theta}{2c}$. Therefore, $q_{nr} = q_R$ at $\hat{\theta}$. As q_{nr} is constant and q_R increases with θ, for all $\theta > \hat{\theta}$, $q_{nr} < q_R$. Therefore, q_R has to intersect q_{nr} from below at $\hat{\theta}$.

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3. As $q_{nr} = \frac{\hat{\theta}+c}{2c}$, we get that $\frac{\partial q_{nr}}{\partial \hat{\theta}} = \frac{1}{2c} > 0$. Thus, q_{nr} increases linearly in $\hat{\theta}$.

□

Lemma 13. *$\theta_h \in R^c$, i.e. the highest type in the type space will never reveal.*

Proof. Firm A of type θ_h will not deviate and reveal, as firm B's strategy would become $q_R = \frac{\theta_h+c}{2c}$ upon revelation as discussed earlier in the PBEM. By not revealing and adopting its technology, firm A's payoff would be $(\theta_h + c) - q_{nr}c$ which is strictly greater than the revelation payoff of $(\theta_h + c) - q_R c = \frac{\theta_h+c}{2}$.Thus, type θ_h would not reveal. □

We have thus shown that the non-revelation set R^c contains θ_h. Consider the subset R^h of R^c which contains θ_h. So $R^h = [\theta', \theta_h] \subset R^c$. No type in this subset reveals in their type in equilibrium. Now, suppose R^h is contiguous with a revelation range. Therefore, θ', the infimum of the set R^h, has to be indifferent between revelation and non-revelation.

Lemma 14. *If a revelation range is contiguous with R^c, then the infimum of the set containing θ_h must coincide with $\hat{\theta}$, i.e. $\theta' = \hat{\theta}$.*

Proof. If $\theta' > \hat{\theta}$, then firm A would prefer not to reveal and adopt rather than reveal as $(\theta' + c) - q_{nr}c > (\theta' + c) - q_R c$. This is because $q_{nr} < q_R$ for all $\theta > \hat{\theta}$. If $\theta' < \hat{\theta}$, then type θ' would prefer not to reveal and switch getting a payoff of $q_{nr}c$ as opposed to $q_R c$ if it revealed, where $q_{nr} > q_R$ for all $\theta < \hat{\theta}$.

It is only for $\hat{\theta} = \theta'$ that $q_R = q_{nr}$ and the payoffs from revelation and non-revelation are the same, making θ' indifferent between these strategies. □

Lemma 15. *There cannot be a contiguous revelation range with R^h. R^c is an continuous interval with θ_h in it.*

Proof. Consider any $\tilde{\theta} = \theta' - \epsilon$, where ϵ is vanishingly small. Whereas θ' is indifferent between revealing and not revealing (it is the infimum of R^h), $\tilde{\theta}$ reveals its type as it is in the contiguous revelation range. However, for all $\theta < \hat{\theta} = \theta'$, $q_{nr} > q_R$ ensuring that by deviating from revelation, $\tilde{\theta}$ can get a higher payoff (switching without revealing will give a payoff $q_{nr}c > q_R c$). Thus, $\tilde{\theta}$ will not reveal. This proves that there cannot be any contiguous range of revelation with $R^h \subset R^c$. As we can show deviations from revelation for any $\tilde{\theta}$ contiguous with the non-revelation set which contains θ_h, the non-revelation set R^c is a continuous interval and not a finite union of disjoint intervals. □

Proposition 16. *Non-revelation is unique in the class of disclosure strategies where A reveals its type over R (either a continuous interval or a finite union of disjoint intervals).*

Proof. Lemma 4 proves that as long as θ_h is an element of the non-revelation interval, no type below it will reveal in equilibrium. Lemma 2 proves that θ_h will never reveal and will always belong to R^c. Hence, the only equilibrium over the disclosure set R involves no information revelation. □

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