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Double-edged transparency in teams

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ABSTRACT

In a team project with significant complementarities between various players' individual tasks, news of early success by some encourages others to push ahead with their own tasks while lack of success has the opposite effect. This ex-post disparity in incentives created gives rise to two differing implications, ex ante, for an ideal team transparency. Sometimes it is better to commit to complete *secrecy* within the team of the various participants' interim progress as it mitigates the negative effect of failures. In some other situations, commitment to full *disclosure* is better as players are then encouraged to be proactive by exerting efforts in the early rounds and motivate other team members into continued activities by way of interim progress. Transparency (of outcomes) has thus double edges – it can boost incentives or dampen incentives.

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1. Introduction

In any organization transparency of activities, progress and procedures (or the lack of it) shape important incentives for its key members. A popular view is that an organization should be transparent. Several contributions have already shown why taking an unqualified stand on this subject could be wrong.¹ In this paper, we highlight a novel and confounding implication of transparency in a team context involving players who engage in a multi-task project with significant complementarities.

We consider a two-agent joint (or team) project with observable efforts. Each agent's effort influences the probability of success of the specific task assigned to him. The overall project is successful only if both tasks are successful. The agents are allowed two attempts to complete their tasks. While a team member is able to observe his partner's first attempt, its outcome, i.e., whether it is successful or not, can be credibly conveyed only by the organization (or the team manager).^{2,3} This setup is

not unnatural and is becoming a more acceptable description of some work environments: (i) mutual observability of efforts can be a distinguishing property of certain types of team works, for instance in software development sometimes important members may be seated in a 'war room' or 'dedicated project room', known as *team collocation*, to facilitate rapid progress of the tasks that are complementary in nature;⁴ and (ii) although the supervisor (or the project leader) may not always observe efforts, he will have the special expertise to determine the state of progress of various tasks. We also consider a variant model where efforts are not observable within the team.

An example is an R&D team project broken down into different components, all of which must work for the composite to succeed.⁵ Researchers often make several attempts to crack a problem. Lack of progress in the initial stages may be suppressed to keep team morale high; also, if one component meets early success, the news, while morale-boosting, might be suppressed to prevent crucial methodological

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¹ See Angeletos and Pavan (2004), Bac (2001), Fang and Moscarini (2005), Gavazza and Lizzeri (2007, 2009), Levy (2007a,b), Mattozzi and Merlo (2007), and Prat (2005).

² Given the obvious motive of encouraging partners into actions, any claim to success by a team member is always going to be viewed with due skepticism.

³ In several works, Winter (2004, 2006, 2009, 2010) analyzes team settings with complementarity between various members' tasks and each member having only one opportunity to attempt his task. The main focus of his papers are on the design of effort-inducing rewards/incentives under observable as well as unobservable efforts, with the former giving rise to sequential efforts and the latter corresponding to simultaneous efforts; the effort outcomes in his models are not observable until at the very end. On incentive design with complementarities across tasks but in a principal-agent setting (rather than team setting), see MacDonald and Marx (2001).

⁴ Teasley et al. (2002) study the positive impact of collocation on team productivity. See also Eccles et al. (2010). The environment of observable efforts (i.e., collocation) and its implications for team incentives is the main focus of *peer transparency* studied in a field experiment paper by Falk and Ichino (2006), two recent theoretical papers by Winter (2006, 2010) as cited above, and the work of Mohnen et al. (2008).

⁵ Projects of this nature are quite common in the industries, especially in software engineering or in the development of any new product or technology. Academic researchers in some disciplines carry out collaborative projects with considerable complementarities under the supervision of a project leader who oversees project development and coordination.

information from leaking out to competitors.⁶ The organization, however, cannot make selective reports on progress, choosing only to announce “good news”, otherwise team members can deduce the state of the project from the level of publicity, in the sense of Milgrom (1981). Suppose that the organization aims to maximize the probability of the project's success. Should it always disclose its information about the project's up-to-date progress?⁷

Clearly, an agent with a failed first attempt will find the information about another agent's success/failure relevant. An early success by another team member can conceivably embolden an agent to exert effort in the second stage, while failure can discourage him. Thus, committing to a policy of disclosure may have sharply divergent results for the manager. Concealing the information, on the other hand, may narrow this divergence. This occurs because, absent this information on outcomes, an agent will be left to *infer* the occurrence of success or failure, i.e., their likelihoods, from his partner's first-period effort choice.

We are going to argue that a policy of disclosure may not always be preferred. First, with disclosure we derive an equilibrium where both agents exert effort in the first round, and if one fails then he exerts effort once more provided the other agent has been successful in the first round. Next, we analyze the situation where only first-round effort choices, but not the outcomes, are observable. We find that if the effort cost is non-negligible but moderately low, secrecy weakly improves on disclosure by *uniquely* implementing in subgame perfect equilibrium the maximal individual and collective efforts over the two rounds (which is also an equilibrium under disclosure along with another equilibrium involving lower efforts). However, for higher costs disclosure may have a very different impact: rather than chancing their luck with little efforts in the early rounds in the case of secrecy, with disclosure the agents tend to be proactive by exerting efforts in the early rounds so that any individual success prompts others to continue with their efforts in the later stages. So there is a double edge to transparency of outcomes – it can boost incentives or dampen incentives.

The confounding implications of transparency in this paper further demonstrate the complexity of the issue. On this subject, Prat (2005) had first pointed out the importance of distinguishing between transparency of *actions* and transparency of the *consequences of actions*. In a principal–agent model where the agent is motivated by career concerns, the principal benefits by committing to learn only about the consequences of the agent's action and not the action itself. With the agent's ability unknown to both the principal and the agent, if the principal observes the agent's action then the agent may disregard his own signal of a payoff relevant state (from the principal's point of view) and choose an action that a high-ability type might be expected to select (state and outcome, along with the agent's ability, jointly determine the principal's payoff), thus hindering the principal from discerning the agent's ability.

In a different principal–agent formulation where the principal is informed about the agent's productivity, Fang and Moscarini (2005) have argued that making worker's quality transparent through wage differentiation could either benefit or harm the firm. Specifically, differentiated contracts convey “good news” to some workers about their ability, which raises morale and effort, but “bad news” to others, which depresses morale and effort; the negative effect on output may be large enough to justify offering the same contract to all employees. In

⁶ Even just the news of interim progress of one firm may prompt rival firms into greater activities (as in Choi (1991) where a firm's success in the initial stages, by conveying that the project is feasible, is “good news” to its rival) or discourage them (as in the R&D race of Bag and Dasgupta (1995), where early success reveals a firm to be a “high” type, thereby intimidating weaker firms). Thus there may be other reasons, besides internal incentives, why an organization may prefer secrecy or not.

⁷ Sometimes the supervisor may choose to only occasionally announce the state of progress for reasons other than strategic disclosures, time constraint being one of them. This paper assumes away the time constraint and focuses only on strategic disclosures.

our analysis there is no ability parameter, only efforts matter and the issue is about strategic disclosures of individual successes and failures.

Several other works noted in the introductory paragraph have studied the negative effects of transparency in various applications and especially in politics and bureaucracies. Levy (2007a,b) shows that in committee decisions through voting, transparency of individual votes leads to worse decisions when those casting votes are motivated by career concerns. Mattozzi and Merlo (2007) study the relationship between political transparency and the quality of politicians attracted and show an inverse relationship, i.e., with more transparency quality drops. Gavazza and Lizzeri (2007) have argued that when the service qualities of different public offices are released, demands for better quality providers increase which, in the absence of high-powered incentives, leads to crowding and rationing, ultimately lowering the incentives of high-quality provision. Gavazza and Lizzeri (2009) delve into several subtle and complicated issues of transparency of the political system, of government spending and revenues. The authors argue that while transparency of government spending is beneficial, improved transparency of taxes (i.e., revenues), through better intertemporal smoothing of the tax burden, can paradoxically lead to more wasteful transfer spending by political parties. In a macroeconomic application, Angeletos and Pavan (2004) analyze the welfare effects of varying levels of transparency of some payoff relevant public information in economies with strong complementarities between (a continuum of) agents' investments and the possibility of multiple investment equilibria; greater transparency improves coordination of agent activities, but given that coordination can lead to a collectively good or bad equilibrium, more transparency may be beneficial or harmful. Different from the above literature, Bac (2001) relates transparency of decision making in public offices to opportunities of establishing connections with key officials that may ultimately result in more corruption.

Finally, we would like to make a distinction between transparency in teams as analyzed in this paper and the idea of interim review (or feedback) in multistage tournaments (recent contributions are Aoyagi (2010), Gershkov and Perry (2009), and Goltsman and Mukherjee (2011)) where interim performance evaluations are used as a strategic device to incentivize *competing* players to exert greater efforts over several rounds. In ours, the issue is not about using interim outcomes directly as the basis for a winner-take-all reward, rather the question is whether making first-round outcomes public would help or hinder team members' effort incentives and its effect on the team's success which is a common goal for the team members. Our work is thus closer to the team problems studied by Winter (2004, 2006, 2009, 2010).⁸

In the next section, we provide an outline of the model. In Sections 3 and 4 we analyze the two cases, disclosure and secrecy. Our main results comparing the two mechanisms appear in Section 4. Section 5 concludes. All proofs are relegated to the Appendix, except for the proofs of Lemmas 4 and 5, which are available online.

2. The model

A joint project consists of two tasks, with two agents (henceforth “players”) assigned one task each. The joint project succeeds if and only if both tasks are completed successfully. A player is given a maximum of two periods to successfully complete his task; effort is discrete, costs c per unit, and is perfectly observable. Towards the end of Section 4 we discuss the implications for our analysis if efforts are not observable.

⁸ In Bag and Pepito (2010), we consider issues of peer transparency in teams where team members make repeated efforts towards a joint project. There, outcomes are not observed until at the very end of the project's duration. It is shown that transparency of *efforts* during the project's development is beneficial when efforts are complementary in the project's success but neutral if the efforts are substitutes.

A player's effort influences his task's success as follows. In Round 1, a player decides whether to *exert effort* (one unit) or *shirk* (exert no effort). Denote player *i*'s effort in the first round by e_{i1} , and the probability that his task succeeds given e_{i1} by $p(e_{i1})$. Suppose that for $i = 1, 2$,

$$p(e_{i1}) = \begin{cases} \alpha & \text{if } e_{i1} = 0 \\ \beta & \text{if } e_{i1} = 1 \end{cases}$$

where $0 < \alpha < \beta < 1$.

Players choose their first-round efforts simultaneously, following which each player observes whether his own task has been successful or not but does not observe the outcome of the other player's effort. The principal observes both tasks' outcomes and can credibly and publicly disclose his information to the players, if he wishes to do so, before they choose their second-round efforts. Any decision to reveal or not reveal by the principal is committed to ex-ante, before the players choose first-round efforts. Moreover, any revelation must be instantaneous.

If a player succeeds at the end of Round 1, he has done his part of the project and no longer needs to exert any effort in Round 2. On the other hand, if he fails at the end of Round 1, he has another opportunity to complete his task successfully. As in Round 1, the success probability associated with player *i*'s second-round effort e_{i2} is

$$p(e_{i2} | i\text{'s task failed in Round 1}) = \begin{cases} \alpha & \text{if } e_{i2} = 0 \\ \beta & \text{if } e_{i2} = 1. \end{cases}$$

Again, second-round choices are made simultaneously. At the end of Round 2, the project concludes. If the project succeeds, both players receive a common reward v ; otherwise, they both receive 0.⁹

We look at two versions of this effort investment game. In one version, the principal announces the outcomes of the players' first-round efforts; in a second version, first-round outcomes are not announced. We will call these cases *disclosure* and *secrecy*, respectively.

Note that because a player always knows his own outcome, a disclosure policy where the principal's decision to reveal outcomes is contingent on the realized outcome profile (i.e., reporting is selective) has no bite: given such a report, a player can either deduce the true state after the first period (i.e., it reduces the game to one of disclosure), or infer that he is in one of only two states (which is none other than our secrecy environment). So in our setting, *partial disclosure* policies of this sort (as analyzed in the tournament literature) can be shown to be equivalent to one of our information environments.¹⁰

3. Disclosure

In this version of the game, the principal announces, before Round 2 starts, the outcomes of the players' first-round efforts. Denote "success" by *S* and "failure" by *F*. Further, denote the principal's announcement by $\mathbf{a} = (a_1, a_2)$, where $a_i \in \{S, F\}$, $i = 1, 2$, is the outcome of player *i*'s first-round effort choice. The announcements are assumed to be truthful.

We will analyze the two-round effort investment game backwards, using *Markov perfect equilibrium* (or, *MPE*) as the solution concept, as defined in *Maskin and Tirole (2001)*. Formally, strategies that depend only on the payoff-relevant "state" of the game, rather than the entire "history", are known as *Markov strategies*, alternatively *stationary*

⁹ Common value is a reasonable description if the principal (or the institution organizing the project) gives identical outcome-contingent rewards. The analysis can be easily extended to differential rewards.

¹⁰ *Gershkov and Perry (2009)* consider only binary revelation, disclosure or secrecy, whereas both *Aoyagi (2010)* and *Goltsman and Mukherjee (2011)* additionally allow for partial disclosure. Earlier *Prat (2005)* and *Levy (2007a)* considered only full disclosure or complete secrecy.

strategies. In the disclosure game formulation with observable efforts, first-round outcomes are of direct relevance to determine the payoffs from the players' efforts in the second round and thus called the *state*, whereas first-round efforts can be considered as "bygones", or *history*, unless players use them to play history-dependent strategies (that *Maskin and Tirole* call "bootstrapping") in the second round;¹¹ so a state in our application can be associated with more than one history, and a history can lead to any of multiple states. (Later in the secrecy game with observable efforts the history and the state will coincide, to be defined by first-round efforts.) Any subgame perfect equilibrium (or, SPE) in Markov strategies is called Markov perfect equilibrium. In this paper, we will consider only pure strategy equilibrium.

We want to construct the following equilibrium:

Round 2: if both players fail in Round 1, each will choose to shirk in Round 2; if only one player succeeds in Round 1, then the other player exerts effort in Round 2.

Round 1: both players exert effort in the first round.

We call the second-round, continuation strategy by a player in the above specification, the *reinforcement strategy*, and denote it by $\tilde{e}_{i2}(\mathbf{a})$, $i = 1, 2$.

The reinforcement strategy is one of several outcome-contingent strategies a player may adopt in the second round.

Now start with Round 2. A player who failed in the first round needs to consider two subgames:

- Both players failed in the first round;
- He alone failed in the first round.

(It should be clear that any two subgames with the same first-round outcomes but different first-round actions are the same, as they present identical strategic choices in the subgame and payoffs for any player.)

In the first subgame (call it \mathcal{G}) both players simultaneously choose efforts with the payoff to player *i*, given his effort e_{i2} and player *j*'s effort e_{j2} , given by

$$u_{i2}(e_{i2}, e_{j2}) = p_i(e_{i2})p_j(e_{j2})v - ce_{i2}, \quad i \neq j,$$

and summarized as follows:

		Player 2	
		0	1
Player 1	0	$\alpha^2 v, \alpha^2 v$	$\alpha\beta v, \alpha\beta v - c$
	1	$\alpha\beta v - c, \alpha\beta v$	$\beta^2 v - c, \beta^2 v - c$

Fig. 1. Simultaneous-move game \mathcal{G} .

For the remainder of this section and the paper, we make the following assumption:

Assumption 1. The parameters α, β, v and c are such that the game \mathcal{G} has two Nash equilibria, $\mathbf{e}_\mathcal{G}^* = (0, 0)$ and $\mathbf{e}_\mathcal{G}^* = (1, 1)$. That is, knowing that one's partner has failed in Round 1, a player (who also failed in Round 1) would shirk if the other player shirks and would exert effort if the other player exerts effort.

¹¹ In the introduction of their article, *Maskin and Tirole* point out the extensive focus on history-independent/Markov strategies in the applied game theory literature. Further, they provide various justifications, including bounded rationality, for the appeal of Markov equilibrium.

Thus, in the first subgame, a player does not have a unique optimal action in the second round. The following conditions are both necessary and sufficient for Assumption 1 to hold:

$$\alpha^2 v \geq \alpha \beta v - c, \quad \text{i.e.,} \quad c \geq \alpha(\beta - \alpha)v, \tag{1}$$

and

$$\beta^2 v - c \geq \alpha \beta v, \quad \text{i.e.,} \quad \beta(\beta - \alpha)v \geq c, \tag{2}$$

with at least one of the inequalities strict, since $\alpha < \beta$.

Condition (2) implies that

$$(\beta - \alpha)v - c > 0, \quad \text{i.e.,} \quad \beta v - c > \alpha v. \tag{3}$$

In other words, a player would strictly prefer to work rather than shirk if, after the first round, he has failed but he knows that his partner has succeeded. Thus the assumption that $\mathbf{e}_G^* = (1, 1)$ implies a unique optimal action in the second subgame.

Thus, by Assumption 1 and the implied condition (3), the reinforcement strategies constitute a Nash equilibrium (or, NE) along each subgame. Importantly, in the reinforcement strategy, we assume that if the players reach the game \mathcal{G} then $\mathbf{e}_G^* = (0, 0)$ will be played although $\beta^2 v - c \geq \alpha^2 v$ (i.e., the payoff-dominant NE, $\mathbf{e}_G^* = (1, 1)$, is not chosen). By committing to shirk if the other player has failed, both players are mutually enhancing their incentives to exert efforts in the first round. Coordinating on this inferior equilibrium in the second round thus acts as a disciplining device, which is a standard method in the repeated/dynamic games literature to induce cooperation.¹²

Let us now fold the game back to Round 1, assuming that the players will choose the reinforcement strategy. Denote the strategy space of the simultaneous-move game in Round 1 by $\Sigma = \{0, 1\} \times \{0, 1\}$. For player 1's payoff calculations, consider the various continuation possibilities following any first-round strategies (e_{11}, e_{21}) :

- $\mathbf{a} = (S, S)$ with probability $p(e_{11})p(e_{21})$. Both players receive v .
- $\mathbf{a} = (S, F)$ with probability $p(e_{11})(1 - p(e_{21}))$. No further action is taken by player 1; however, he has to wait one more round (during which player 2 makes another attempt at completing his task) for his payoff to be realized. Note that player 1's payoff will depend on player 2's second-round effort choice, e_{22} . Player 2, for his part, will choose the action that will give him the higher payoff, given that player 1 has succeeded in his task; his payoff from each second-round action following the outcome/announcement $\mathbf{a} = (S, F)$ is

$$u_2((S, F); e_{22}) = \begin{cases} \alpha v & \text{if } e_{22} = 0 \\ \beta v - c & \text{if } e_{22} = 1. \end{cases}$$

By condition (3), following the outcome (S, F) player 2 will choose $e_{22} = 1$ in Round 2; consequently, player 1 will receive the payoff βv .

- $\mathbf{a} = (F, S)$ with probability $(1 - p(e_{11}))p(e_{21})$. No further action is taken by player 2. By the same argument as in the immediately preceding case, player 1 will choose $e_{12} = 1$ in Round 2, for a payoff to player 1 of $\beta v - c$.
- $\mathbf{a} = (F, F)$ with probability $(1 - p(e_{11}))(1 - p(e_{21}))$. The game \mathcal{G} is played. The resulting equilibrium is $\mathbf{e}_G^* = (0, 0)$, and player 1 receives $\alpha^2 v$.

¹² Che and Yoo (2001), for instance, recognize that “the team equilibrium concept relies on the agents’ abilities to select the worst possible (subgame-perfect) punishment.”

So the expected payoff of player 1 in the first-round, simultaneous-move game for each $(e_{11}, e_{21}) \in \Sigma$ is

$$\begin{aligned} Eu_{11}^D(e_{11}, e_{21}) &= p(e_{11})p(e_{21})v + p(e_{11})(1 - p(e_{21}))\beta v \\ &+ (1 - p(e_{11}))p(e_{21})(\beta v - c) \\ &+ (1 - p(e_{11}))(1 - p(e_{21}))\alpha^2 v - ce_{11}. \end{aligned} \tag{4}$$

Remark 1. Note that the payoff in (4) is calculated assuming that the players play some specific Nash equilibrium (or sequentially rational) strategies in the continuation games, whether the continuation games are on or off the equilibrium path. In particular, we do not write the payoffs to be contingent on first-round actions where players select different NE in the continuation game \mathcal{G} depending on actions. Fixing an equilibrium (or a sequentially rational strategy) in any subgame is due to our restriction that the players play only Markov strategies.

Denote the reduced one-shot game, when there is disclosure, by \mathcal{G}_1^D . For convenience, let $Eu_{11}^D(0, 0) = x$, $Eu_{11}^D(1, 0) = w$, $Eu_{11}^D(0, 1) = y$, and $Eu_{11}^D(1, 1) = z$ (by symmetry, player 2's expected payoffs in the reduced game are similarly defined). Then the first-round efforts under disclosure are given by the NE of \mathcal{G}_1^D :

		Player 2	
		0	1
Player 1	0	x, x	y, w
	1	w, y	z, z

Fig. 2. Simultaneous-move game \mathcal{G}_1^D .

Using (4), write

$$\begin{aligned} z &= \beta^2 v + \beta(1 - \beta)\beta v + (1 - \beta)\beta(\beta v - c) + (1 - \beta)(1 - \beta)\alpha^2 v - c, \\ y &= \alpha \beta v + \alpha(1 - \beta)\beta v + (1 - \alpha)\beta(\beta v - c) + (1 - \alpha)(1 - \beta)\alpha^2 v. \end{aligned}$$

Assuming players choose the reinforcement strategies $\tilde{e}_{12}(\mathbf{a})$, an NE in the reduced game will involve both players exerting effort in the first round, that is, $\mathbf{e}_{\mathcal{G}_1^D}^* = (1, 1)$ (this will then constitute an MPE in the extensive-form game with disclosure) if and only if

$$\begin{aligned} & z \geq y \\ \text{i.e.,} & (\beta - \alpha)\beta v + (\beta - \alpha)(1 - \beta)\beta v - c \geq (\beta - \alpha)\beta(\beta v - c) + (\beta - \alpha)(1 - \beta)\alpha^2 v \\ \text{i.e.,} & \frac{(\beta - \alpha)[(2\beta - \alpha^2)(1 - \beta)]}{1 - \beta(\beta - \alpha)} v \geq c \\ \text{i.e.,} & (\beta - \alpha)g(\alpha, \beta)v \geq c, \end{aligned} \tag{5}$$

$$\text{where } g(\alpha, \beta) = \frac{(2\beta - \alpha^2)(1 - \beta)}{1 - \beta(\beta - \alpha)}.$$

Thus, we obtain the following result:

Lemma 1. Under the policy of disclosure, $(1, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$ will be an MPE if and only if the cost parameter c satisfies (1), (2), and (5), i.e., c satisfies, for given v, α , and β ,

$$\alpha(\beta - \alpha)v \leq c \leq \min\{\beta(\beta - \alpha)v, (\beta - \alpha)g(\alpha, \beta)v\}, \tag{6}$$

with at least one of the inequalities strict if $\min\{\beta(\beta-\alpha)v, (\beta-\alpha)g(\alpha, \beta)v\} = \beta(\beta-\alpha)v$.

Example 1. Suppose that $\beta = 0.7, \alpha = 0.3$, and $v = 10$. Then it is easy to check that Assumption 1 is satisfied (i.e., (1) and (2) will hold) if and only if $c \in [1.2, 2.8]$, and that $(1, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$ is an MPE under disclosure if and only if $c \in [1.2, 2.18333]$ (so that (5) also holds) as shown in Lemma 1. Note that relative to the continuation game \mathcal{G} , inducing efforts by both players in the first round is more difficult (the upperbound of c shrinks) as players can take a chance by shirking early on in the play. The cost cannot be too low either as otherwise exerting effort in the second round becomes a dominant strategy and the reinforcement strategy will no longer be an NE in the continuation game. □

4. Secrecy: better or worse?

We assume, as in the previous section, that the players' efforts are observable. Our main concern is about the transparency of outcomes. Also, we continue to impose Assumption 1, so conditions (1) and (2) (and by implication (3)) will be assumed to hold. Towards the end, we will relax the assumption on observability of efforts.

When the principal commits to secrecy of outcomes, the game proceeds as follows:

Round 1. Players simultaneously choose their first-round efforts, $e_{i1} \in \{0, 1\}, i = 1, 2$. If a player succeeds in the first round, then he exerts no further effort; if the player fails, then he proceeds to Round 2 with the information gained during an *Interim period*.

Interim period. First-round efforts, $\mathbf{e}_1 = (e_{11}, e_{21}) \in \{(0, 0), (0, 1), (1, 0), (1, 1)\}$, are observed by both players (*Transparency of efforts*, the default scenario). Further, each player knows the outcome of his first attempt, i.e., whether he has succeeded or failed, but does not know the outcome of the other player's attempt. However, from e_{j1}

player i can infer that player j succeeded with probability $p(e_{j1})$ and failed with probability $(1 - p(e_{j1}))$.

Round 2. A player again either shirks or exerts effort, and the expected continuation payoffs are calculated based on his beliefs about the other player's success.

At the end of Round 2 the two tasks' final outcomes determine the project's overall outcome and the players receive their payoffs. □

The game tree is presented in Fig. 3.

We solve this extensive-form game backwards just like in the disclosure game, but this time the Markov restriction on strategies does not have any bite because the history (defined by first-round efforts) and the state are one and the same thing; first-round efforts will define the state, with outcomes not disclosed anymore. Therefore the solution concept is SPE. Although in this game SPE and MPE are equivalent, we prefer to use the former terminology.

Fixing Round 1 efforts at any $\mathbf{e}_1 = (e_{11}, e_{21})$, consider the continuation game for player 2, i.e., the game he would face having failed in Round 1.

- Player 2's payoff from second-round effort choice, e_{22} , depends on his beliefs about player 1's success or failure in Round 1. Given e_{11} , player 2's expected payoff from $e_{22} = 0$ is

$$Eu_{22}(e_{22} = 0) = \begin{cases} p(e_{11})\alpha v + (1-p(e_{11}))\alpha^2 v & \text{if } e_{12} = 0 \\ p(e_{11})\alpha v + (1-p(e_{11}))\alpha\beta v & \text{if } e_{12} = 1, \end{cases}$$

and his expected payoff from $e_{22} = 1$ is

$$Eu_{22}(e_{22} = 1) = \begin{cases} p(e_{11})(\beta v - c) + (1-p(e_{11}))(\alpha\beta v - c) & \text{if } e_{12} = 0 \\ p(e_{11})(\beta v - c) + (1-p(e_{11}))(\beta^2 v - c) & \text{if } e_{12} = 1. \end{cases}$$

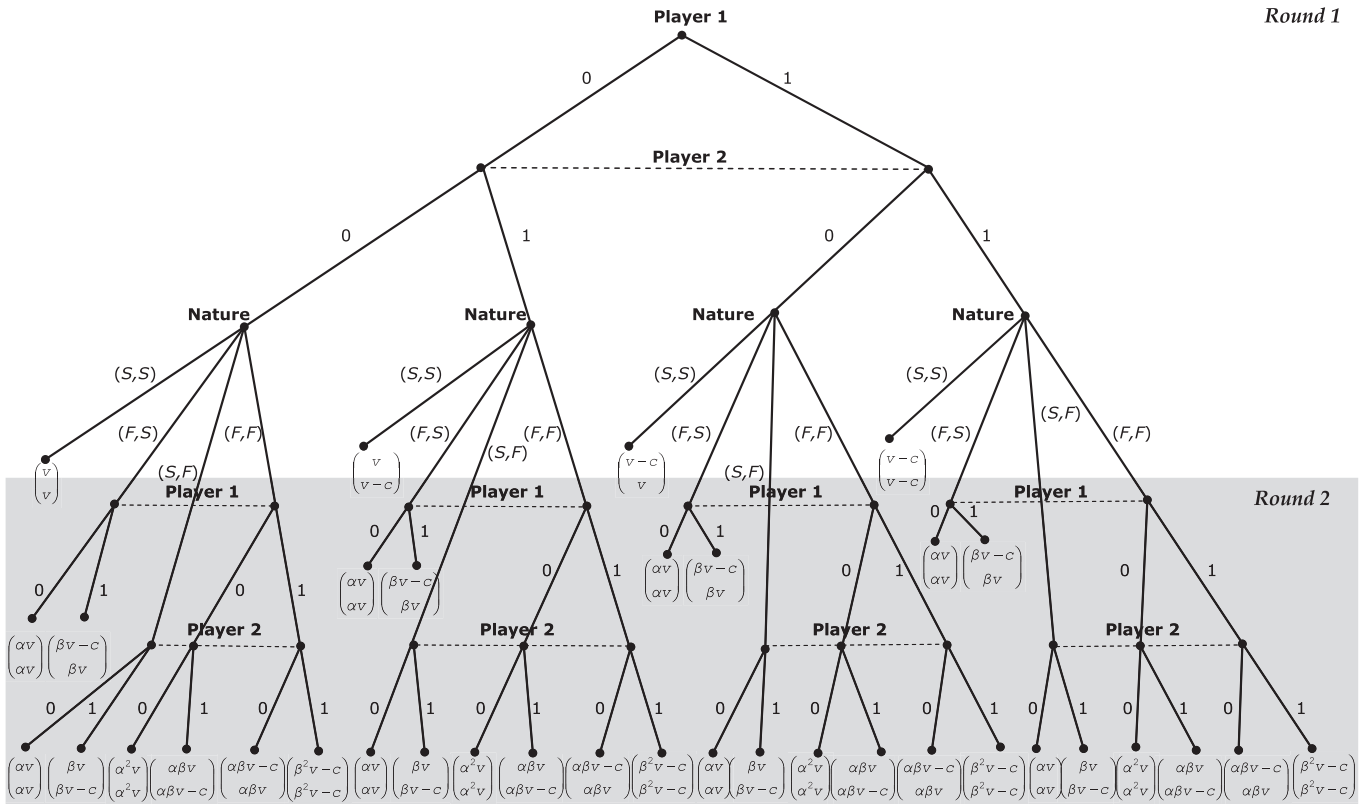


Fig. 3. The secrecy game.

		0	1
	P2		
		0	1
P1	0	$p(e_{21})\alpha v + (1 - p(e_{21}))\alpha^2 v,$ $p(e_{11})\alpha v + (1 - p(e_{11}))\alpha^2 v$	$p(e_{21})\alpha v + (1 - p(e_{21}))\alpha\beta v,$ $p(e_{11})(\beta v - c) + (1 - p(e_{11}))(\alpha\beta v - c)$
	1	$p(e_{21})(\beta v - c) + (1 - p(e_{21}))(\alpha\beta v - c),$ $p(e_{11})(\alpha v) + (1 - p(e_{11}))(\alpha\beta v)$	$p(e_{21})(\beta v - c) + (1 - p(e_{21}))(\beta^2 v - c),$ $p(e_{11})(\beta v - c) + (1 - p(e_{11}))(\beta^2 v - c)$

Fig. 4. Simultaneous-move game $\mathcal{G}_{e_1}^S$.

- Similarly, if player 1 fails in Round 1 and knowing that player 2 chose e_{21} , his expected payoff from $e_{12} = 0$ is

$$Eu_{12}(e_{12} = 0) = \begin{cases} p(e_{21})\alpha v + (1 - p(e_{21}))\alpha^2 v & \text{if } e_{22} = 0 \\ p(e_{21})\alpha v + (1 - p(e_{21}))\alpha\beta v & \text{if } e_{22} = 1, \end{cases}$$

and his expected payoff from $e_{12} = 1$ is

$$Eu_{12}(e_{22} = 1) = \begin{cases} p(e_{21})(\beta v - c) + (1 - p(e_{21}))(\alpha\beta v - c) & \text{if } e_{22} = 0 \\ p(e_{21})(\beta v - c) + (1 - p(e_{21}))(\beta^2 v - c) & \text{if } e_{22} = 1. \end{cases}$$

Denote the “simultaneous-move” game that is played in the second round when one or both players failed in the first round but are only able to observe \mathbf{e}_1 , by $\mathcal{G}_{e_1}^S$. Based on our derivations above, the game $\mathcal{G}_{e_1}^S$ takes the form of Fig. 4.

Remark 2. Under maintained assumptions, $\mathcal{G}_{e_1}^S$ has no asymmetric (pure strategy) equilibrium.

The strategy profile (1, 0) is an asymmetric equilibrium of $\mathcal{G}_{e_1}^S$ only if

$$p(e_{11})(\alpha v) + (1 - p(e_{11}))(\alpha\beta v) \geq p(e_{11})(\beta v - c) + (1 - p(e_{11}))(\beta^2 v - c),$$

i.e., $0 \geq p(e_{11})((\beta - \alpha)v - c) + (1 - p(e_{11}))(\beta(\beta - \alpha)v - c),$

which contradicts conditions (2) and (3), combined. By the same argument, the strategy profile (0, 1) cannot be an NE.

We see that asymmetric equilibria do not arise in any $\mathcal{G}_{e_1}^S$. Moreover, for any player i , if player j chooses $e_{j1} = 1$, player i is strictly better off choosing $e_{i1} = 1$ instead of $e_{i1} = 0$, applying (2) and (3) and the fact that $0 < \alpha < \beta < 1$. We can therefore state the following result:

Corollary 1. Suppose Assumption 1 holds. Then $\mathbf{e}_{\mathcal{G}_{e_1}^S}^* = (1, 1)$ for any \mathbf{e}_1 .

This should not be surprising. Recall that, by Assumption 1, $\mathbf{e}_{\mathcal{G}}^* = (1, 1)$, so in the case of disclosure when both players fail in Round 1 it is in the best interest of any player to exert effort in the second round provided that the other player does the same. With secrecy, such an incentive remains, and in fact it is sharpened, since now he believes that his partner's first attempt, even a perfunctory one, might have succeeded with some probability (in which case making sure his own task is completed by exerting effort surely pays).

Let us now turn to the first round. Denote the reduced one-shot game, when there is secrecy, by \mathcal{G}_1^S , and a strategy profile under secrecy by $\mathbf{e}_{\mathcal{G}_1^S}^* = (e_{11}^S, e_{21}^S; e_{12}^S, e_{22}^S)$, where e_{i2}^S is an unsuccessful player i 's second-round action. Denote the equilibrium (or, SPE) of this reduced game by $\mathbf{e}_{\mathcal{G}_1^S}^*$. Analyzing first-round choices and their corresponding continuation games then leads to the following results.

Lemma 2. Consider the game under secrecy. Suppose Assumption 1 holds. Then:

[L2a] $\mathbf{e}_{\mathcal{G}_1^S}^* = (1, 1; 1, 1)$ (i.e., both players exerting effort in the first round, followed by any player with an unsuccessful first attempt exerting effort in the second round, is an SPE) if and only if

$$c \leq \frac{\beta(\beta - \alpha)(2 - \beta)(1 - \beta)}{1 - (\beta - \alpha)}v. \tag{7}$$

[L2b] In the continuation game $\mathcal{G}_{(1,1)}^S$, (1, 1) is the unique (strict) dominant strategy equilibrium.¹³ That is, for each player, exerting effort in the second round regardless of the other player's second-round action (if the other player has indeed failed in the first round) is a strict best response in $\mathcal{G}_{(1,1)}^S$.

In contrast to the reinforcement strategy in the disclosure case where a player exerts effort in the second round only if the other player succeeded in the first round, in the continuation game $\mathcal{G}_{(1,1)}^S$ exerting effort is a “(strictly) dominant strategy”, i.e., any player would do strictly better to exert effort (rather than shirk) even though his partner shirks. This is because the probability of success of his partner's first-round action (which was to put in effort) is large enough such that the additional payoff from exerting effort, given that the other player has succeeded, outweighs the loss from putting in effort when the other player has in fact failed (recall, (0, 0) is an NE in the game \mathcal{G}) and chooses to shirk in the second round.¹⁴ Note that the dominance of effort over shirking in the continuation game is possible because of secrecy.

Lemma 3. Suppose Assumption 1 holds. Then under secrecy, $\mathbf{e}_{\mathcal{G}_1^S}^* = (0, 0; 1, 1)$ (i.e., both players shirking in the first round, followed by any player with an unsuccessful first attempt exerting effort in the second round, is an SPE) if and only if

$$\frac{(\beta - \alpha)[\beta + \alpha(1 - \beta)](1 - \beta)}{1 - (\beta - \alpha)}v \leq c. \tag{8}$$

We are ready to report one of our main results.

Proposition 1 (Secrecy dominates Disclosure). Suppose that, given α, β, v and c , and $\alpha < \beta$, the following conditions hold:

$$\alpha(\beta - \alpha)v \leq c \leq \beta(\beta - \alpha)v \tag{9}$$

with at least one inequality strict (which is Assumption 1), and

$$c < \frac{(\beta - \alpha)[\beta + \alpha(1 - \beta)](1 - \beta)}{1 - (\beta - \alpha)}v. \tag{10}$$

¹³ See Osborne (2004, Section 2.7.8) for a definition of strict equilibrium.

¹⁴ The continuation game under secrecy is an imperfect information game: in the second round, a player may be the only player choosing an effort decision and yet not know that the other player has succeeded in the first round.

Then:

[P1a] Under disclosure, $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* = (1, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$: both players exerting effort in the first round, followed by the reinforcement strategy, is an MPE. Also, $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* = (1, 1; 1, 1)$.

[P1b] Under secrecy, the unique SPE is $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* = (1, 1; 1, 1)$.

Condition (9), which is Assumption 1, allows us to determine the equilibrium that will be played in any continuation game (by Corollary 1). Given that (9) holds, condition (10) supports the disclosure equilibria $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* = (1, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$ and $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* = (1, 1; 1, 1)$, as well as uniqueness of the secrecy equilibrium $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* = (1, 1; 1, 1)$.

The domination result in Proposition 1 is in a weak sense: secrecy retains the best equilibrium under disclosure and eliminates all worse effort pairs. Further discussion of Proposition 1 is postponed until after Proposition 2. Next we consider the possibility of disclosure dominating secrecy.

In the disclosure case, denote the subgame where player i is the only unsuccessful player following the first round by \mathcal{F}_i . Other than the reinforcement strategy $\tilde{e}_{12}(\mathbf{a})$ (in which player i shirks in \mathcal{G} and exerts effort in \mathcal{F}_i), there are three other possible continuation strategies under disclosure for player i when he has failed in the first round: (i) shirk in both \mathcal{G} and \mathcal{F}_i ; (ii) exert effort in \mathcal{G} and shirk in \mathcal{F}_i ; and (iii) exert effort in both \mathcal{G} and \mathcal{F}_i . By condition (3) (which follows from Assumption 1), a player would prefer to exert effort rather than shirk in \mathcal{F}_i . Thus (i) and (ii) cannot be part of an MPE, and the only permissible continuation strategies for a player under disclosure are $\tilde{e}_{12}(\mathbf{a})$ and (iii) above (call this strategy $\hat{e}_{12}(\mathbf{a})$). Players may follow asymmetric continuation strategies. Therefore, under disclosure the possible strategy profiles in the second round are $(\tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$, $(\hat{e}_{12}(\mathbf{a}), \hat{e}_{22}(\mathbf{a}))$, and $(\tilde{e}_{12}(\mathbf{a}), \hat{e}_{22}(\mathbf{a}))$. However, $(\tilde{e}_{12}(\mathbf{a}), \hat{e}_{22}(\mathbf{a}))$ (i.e., one player following the reinforcement strategy while the other exerts effort irrespective of his partner's outcome) cannot be part of a disclosure MPE. If it were, then (1,0) would be an NE in the game \mathcal{G} , which is an impossibility given that $\alpha < \beta$, since this requires (refer to Fig. 1):

$$\begin{aligned} \alpha\beta v - c &\geq \alpha^2 v && \Rightarrow \alpha(\beta - \alpha)v \geq c \\ \text{and } \alpha\beta v &\geq \beta^2 v - c && \Rightarrow c \geq \beta(\beta - \alpha)v. \end{aligned}$$

Therefore, other than $(1, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$, the remaining disclosure equilibrium candidates are:

- [1] $(1, 1; \hat{e}_{12}(\mathbf{a}), \hat{e}_{22}(\mathbf{a}))$; [2] $(1, 0; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$; [3] $(1, 0; \hat{e}_{12}(\mathbf{a}), \hat{e}_{22}(\mathbf{a}))$;
- [4] $(0, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$; [5] $(0, 1; \hat{e}_{12}(\mathbf{a}), \hat{e}_{22}(\mathbf{a}))$; [6] $(0, 0; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$;
- [7] $(0, 0; \hat{e}_{12}(\mathbf{a}), \hat{e}_{22}(\mathbf{a}))$.

Now consider the equilibrium $(0, 0; 1, 1)$ under secrecy (which obtains under condition (8)), and compare each of the candidate equilibria under disclosure listed above to this strategy profile. In candidate equilibrium [7], both players shirk in the first round, and each player, should he fail, exerts effort in the second round irrespective of the other player's outcome; thus this strategy profile, and $(0, 0; 1, 1)$ under secrecy, are the same. The strategy profiles [1], [3], and [5] are clearly superior: in the continuation strategy in each of these profiles, both players exert effort irrespective of the other player's outcome (same as in $(0, 0; 1, 1)$ under secrecy) and at least one player is being proactive by exerting effort in the earlier round (whereas in $(0, 0; 1, 1)$ under secrecy, both players shirk in Round 1). The remaining strategy profiles (namely, $(1, 0; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$, $(0, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$, and $(0, 0; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$) are either inferior, or do not yield an obvious comparison. We can now make the following claim.

Proposition 2 (Disclosure dominates Secrecy). Suppose that, given α, β, v and c , and $\alpha < \beta$, the following conditions hold:

$$\alpha(\beta - \alpha)v \leq c \leq \beta(\beta - \alpha)v \tag{11}$$

with at least one inequality strict (which is Assumption 1),

$$c > \frac{\beta(\beta - \alpha)(2 - \beta)(1 - \beta)}{1 - (\beta - \alpha)}v, \tag{12}$$

and

$$\begin{aligned} c < \min \left\{ (\beta - \alpha)g(\alpha, \beta)v, \frac{(\beta - \alpha) \left[(2\beta - \alpha^2)(1 - \alpha) - (\beta - \alpha) \right]}{1 - \alpha(\beta - \alpha)}v \right\} \\ = \min \{ (\beta - \alpha)g(\alpha, \beta)v, (\beta - \alpha)h(\alpha, \beta)v \}, \end{aligned} \tag{13}$$

where $g(\alpha, \beta)$ is defined in Section 3 and $h(\alpha, \beta) = \frac{[(2\beta - \alpha^2)(1 - \alpha) - (\beta - \alpha)]}{1 - \alpha(\beta - \alpha)}$. Then:

[P2a] (**Proactive outcome**) Under disclosure, $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* = (1, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$: both players exerting effort in the first round, followed by the reinforcement strategy, is an MPE.

[P2b] (**Opportunistic play**) Under secrecy, $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* = (0, 0; 1, 1)$.

[P2c] Under secrecy, $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* \neq (1, 1; 1, 1)$, $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* \neq (1, 1; 1, 0)$, $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* \neq (1, 1; 0, 1)$, $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* \neq (1, 0; 1, 1)$, $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* \neq (1, 0; 1, 0)$, and $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* \neq (1, 0; 0, 1)$: strategy profiles that involve at least one player exerting effort in the first round, followed by at least one player exerting effort in the second round, cannot be SPE.

[P2d] Under disclosure, $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* \neq (1, 0; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$, $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* \neq (0, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$, and $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* \neq (0, 0; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$.

Given Assumption 1 (condition (11)), the rest of the conditions facilitate the following. Condition (13) supports $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* = (1, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$, and (12) supports $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* = (0, 0; 1, 1)$. Secrecy SPE that are superior to the disclosure equilibrium $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* = (1, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$ (identified in [P2c]) are eliminated, using either (11) or (12). Finally, disclosure MPE that are inferior to $\mathbf{e}_{\mathcal{G}\mathcal{P}}^* = (0, 0; 1, 1)$ (identified in [P2d]) are eliminated, through condition (13).

Proposition 1 presents plausible scenarios where secrecy dominates disclosure, whereas Proposition 2 presents the opposite possibility.¹⁵ The intuitions are as follows. In the disclosure MPE, efforts are sustained in the first round because of the threat of punishment (following mutual failures in the first round players coordinate on the (0,0) Nash equilibrium rather than (1,1) equilibrium in the continuation game), whereas with secrecy, any of two possibilities may happen. First, early activity by both players (i.e., (1,1) in the first round) may be encouraged although there is no implied penalty for shirking in the form of playing the 'bad' equilibrium in the continuation game (as in the disclosure case), mainly to keep the other player motivated should he need to make a second attempt. If c is moderately low, then $(1, 1; 1, 1)$ remains the unique SPE because savings in effort costs by shirking in the first round generally do not justify the fall in expected benefits for a player along alternative continuation paths (first-round deviation by a player can be followed up by more than one strategy in the second round). On the other hand, for c large enough, a player would rather save in first-round effort costs and take a chance with the first-round draw and put in the effort in the last round if first round proves unsuccessful, giving rise to $(0, 0; 1, 1)$ equilibrium. Note that because

¹⁵ The domination in Proposition 1 is in the weak sense, whereas in Proposition 2 we can apply only strict domination. While the secrecy equilibrium strategies, $(1, 1; 1, 1)$, translate naturally in the disclosure game, there is no directly comparable strategy profile in the secrecy game corresponding to the disclosure equilibrium strategies $(1, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$.

of high c it is possible that, under secrecy, $(0,0;0,0)$ is an SPE, which further serves to strengthen the dominance of the disclosure equilibrium (i.e., $(1, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$).¹⁶

Example 2. [Double-edged transparency]. Suppose that, as in Example 1 in Section 3, $\beta=0.7$, $\alpha=0.3$, and $v=10$. Recall that, for these parameter values, $\alpha(\beta-\alpha)v=1.2$ and $\min\{\beta(\alpha-\alpha)v, (\beta-\alpha)g(\alpha, \beta)v\} = (\beta-\alpha)g(\alpha, \beta)v=2.18333$, so that $(1, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$ is an MPE under disclosure if and only if $c \in [1.2, 2.18333]$ (refer to Lemma 1).

According to the critical values for c identified in Propositions 1 and 2, we can split the interval, $c \in [1.2, 2.18333]$, further into three sub-intervals depending on whether one or both of the secrecy SPE analyzed here emerges. We plot these critical values for c against $\alpha \in (0, \beta)$ in Fig. 5.¹⁷ One can check that at $\alpha=0.3$, $\frac{(\beta-\alpha)[\beta + \alpha(1-\beta)](1-\beta)}{1-(\beta-\alpha)}v = 1.58$, $\frac{\beta(\beta-\alpha)(2-\beta)(1-\beta)}{1-(\beta-\alpha)}v = 1.82$, and $(\beta-\alpha)h(\alpha, \beta)v = 2.35$ (these bounds appear in conditions (10), (12) and (13), respectively). Therefore,

- Secrecy dominates disclosure if $c \in [1.2, 1.58]$, and
- disclosure dominates secrecy if $c \in (1.82, 2.18333]$;
- if $c \in [1.58, 1.82]$ (as indicated by the cross-hatched region), then under secrecy both $(1, 1; 1, 1)$ and $(0, 0; 1, 1)$ are SPE.

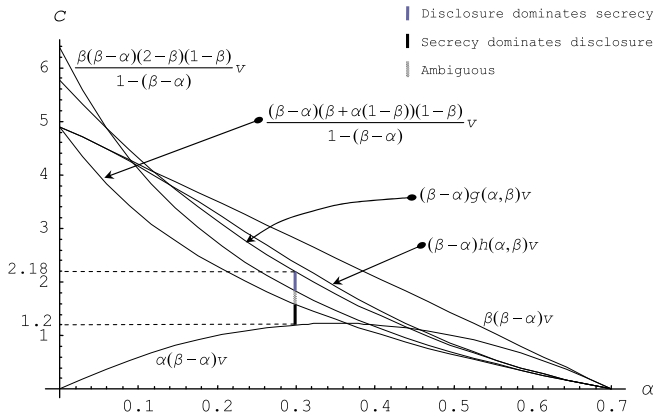


Fig. 5. Double-edged transparency for $v=10$, $\beta=0.7$, and $\alpha=0.3$.

In the intermediate range $c \in [1.58, 1.82]$, the secrecy equilibrium $(1, 1; 1, 1)$ is better than the disclosure equilibrium $(1, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$, while the secrecy equilibrium $(0, 0; 1, 1)$ is worse. Thus for these intermediate c values, a clear ranking is not possible: secrecy may either enhance or weaken players' effort incentives.

Overall, not disclosing outcomes helps to eliminate a player's tendency to give up on the project following failure in the early stage, whereas disclosure of outcomes incentivizes players to be pro-active in exerting efforts early and be successful in their own tasks so that others are encouraged to follow suit. □

Role of Assumption 1. Both players exerting effort in the first round in our constructed equilibrium (under disclosure) is achieved when there are multiple equilibria in the continuation game, \mathcal{G} , but the players coordinate on the bad equilibrium $\mathbf{e}_{\mathcal{G}}^* = (0, 0)$. Somewhat surprisingly, the case for both players exerting effort in the first round becomes weaker if, instead, one assumes that $(0, 0)$ is the unique equilibrium in \mathcal{G} . The reason is, shirking by both players being the unique NE in \mathcal{G} implies that the effort cost, c , must be rather high, which in turn weakens first-round effort incentives.

Unobservable efforts. Our analysis so far relied on the assumption of mutual observability of efforts. What happens if efforts are not observable is a natural question to ask.

First note that when outcomes are disclosed, information on first-round efforts is irrelevant – all that matters to a player in Round 2, if he has not been successful in Round 1, is the outcome of the other player's first-round effort rather than the effort itself or his own first-round effort. Thus, as noted earlier in Section 3, any two subgames following identical outcomes but different first-round actions are identical one-shot games. So, in analyzing any particular subgame, non-observability of efforts makes no difference: the NE efforts under observable and non-observable efforts would coincide. Second, when viewed at the start of the game in the first round, on the face of it observability of efforts may potentially make a difference: if a player were to deviate in the first round by choosing a different effort level from the one specified in a hypothetical equilibrium, then in the second round, for any subgame to follow depending on outcomes, the players may adopt strategies different from that specified in the posited equilibrium. However, our equilibrium constructions (and eliminations) in the disclosure game with observable efforts relied on players choosing the same NE (or sequentially rational strategies) in second-round subgames irrespective of first-round actions (the Markov strategy assumption). So, any lack of knowledge of first-round efforts isn't going to alter our original equilibrium construction (or elimination) arguments. Therefore, the set of equilibrium under observable and non-observable efforts will coincide, implying part [P1a] of Proposition 1 and parts [P2a] and [P2d] of Proposition 2 would extend to the case when efforts are not observable.

For the secrecy game, however, effort observability becomes more of an issue. When team members are able to observe first-round efforts but not outcomes, they condition their second-round strategies on first-round efforts. So the subgames are defined in terms of first-round efforts rather than the outcomes; the players engage in a repeated (efforts) contribution game, earlier denoted by \mathcal{G}_1^S .

When efforts are not observable and outcomes are not disclosed, each player privately makes two attempts at his task without any information to condition his decision on in the second round (except his own effort outcome in the first round). Thus, the game is a simultaneous (efforts) contribution game, to be referred simply as \mathcal{G}^S , with NE as the equilibrium definition.

In the repeated efforts game, being able to condition the second-round strategies on first-round efforts can create new equilibria that are not available under the simultaneous move game, or remove existing equilibria of the simultaneous move game by introducing strategies that lead to profitable deviations. So how the equilibrium sets in the two alternative game forms under secrecy differ is not, a priori, clear.

A formal analysis of the simultaneous contribution game yields the following result.

Lemma 4. *If c satisfies the conditions in Proposition 2, then disclosure dominates secrecy, both with and without effort observability.*

On the other hand, the dominance of secrecy over disclosure under the conditions of Proposition 1 may fail when efforts are no longer observable. This is because with unobservable efforts, $(1, 1; 1, 1)$ may no longer be the unique secrecy equilibrium.

Lemma 5. *If c satisfies the conditions in Proposition 1, then secrecy continues to dominate disclosure when efforts are not observable if and only if*

$$c < (\beta-\alpha)[\alpha + (1-\alpha)\alpha]v. \tag{14}$$

One potential downside of non-observability of efforts in the secrecy game is the strong temptation of shirking, especially in the early stage of the game. For instance, when players are considering to play $(0, 0; 0, 0)$ in a hypothetical equilibrium, there is no way a player can deviate and exert an effort in the first round and ensure that it would be reciprocated by the other player in the second round. As a

¹⁶ Note that $(1, 1; 0, 0)$ is not an SPE under secrecy, by Assumption 1.

¹⁷ The figure is generated in 'Mathematica'.

result, (0,0;0,0) may arise in equilibrium. While this is possible for some parameter configurations, if the effort cost is reasonably small as defined by (14), *secrecy* may continue to dominate *disclosure* when efforts are not observable.

Our two main results under observable efforts can thus be extended, as follows.

Proposition 3. (Transparency with unobservable efforts). *Suppose that the players' efforts are not observable. Then transparency of outcomes can boost or weaken effort incentives under appropriate conditions:*

[P3a] *If c satisfies the conditions in Proposition 1, then secrecy continues to dominate disclosure if and only if $c < (\beta - \alpha)[\alpha + (1 - \alpha)\alpha]v$.*

[P3b] *If c satisfies the conditions in Proposition 2, then disclosure continues to dominate secrecy.*

Below we demonstrate the countervailing implications of transparency, as formalized in Proposition 3, by extending our Example 2.

Example 3. Refer to Fig. 5, where we illustrate double-edged transparency with *observable* efforts for $\beta = 0.7$, $\alpha = 0.3$, and $v = 10$. Using Lemma 1 and the conditions in Propositions 1 and 2, we showed that $(1, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$ is an MPE under disclosure if and only if $c \in [1.2, 2.18333]$, and that, within this interval,

- secrecy dominates disclosure if $c \in [1.2, 1.58]$,
- disclosure dominates secrecy if $c \in (1.58, 2.18333]$; and
- if $c \in [1.58, 1.82]$, an unambiguous ranking is not possible.

Note that $(\beta - \alpha)[\alpha + \alpha(1 - \alpha)]v = 2.04$, so the additional constraint (14) is not binding. Therefore, using Proposition 3, all the aforementioned results still hold when efforts are *not observable*.

Next, consider $\alpha = 0.2$, with the rest of the parameter values unchanged. It is easy to check that $\alpha(\beta - \alpha)v = 1$ and $\min\{\beta(\beta - \alpha)v, (\beta - \alpha)g(\alpha, \beta)v\} = (\beta - \alpha)g(\alpha, \beta)v = 3.13846$, so that $(1, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$ (refer to Lemma 1) is an equilibrium under disclosure if and only if $c \in [1, 3.13846]$, both when efforts are *observable* and when *not observable*. Using Propositions 1 and 2, in particular the conditions (10), (12) and (13), respectively, one can check that at $\alpha = 0.2$, $\frac{(\beta - \alpha)[\beta + \alpha(1 - \beta)](1 - \beta)}{1 - (\beta - \alpha)}v = 2.28$, $\frac{\beta(\beta - \alpha)(2 - \beta)(1 - \beta)}{1 - (\beta - \alpha)}v = 2.73$, and $(\beta - \alpha)h(\alpha, \beta)v = 3.27$. Therefore, when efforts are *observable*, within the interval $[1, 3.13846]$,

- secrecy dominates disclosure if $c \in [1, 2.28]$,
- disclosure dominates secrecy if $c \in (2.28, 3.13846]$; and
- if $c \in [2.28, 2.73]$ then under secrecy both $(1, 1; 1, 1)$ and $(0, 0; 1, 1)$ are SPE, so an unambiguous ranking is not possible.

Now let us decompose the same interval $c \in [1, 3.13846]$ when efforts are *not observable*. By part [P3b] of Proposition 3, disclosure continues to dominate secrecy if $c \in (2.73, 3.13846]$. This time, however, since $(\beta - \alpha)[\alpha + \alpha(1 - \alpha)]v = 1.8 < 2.28$, by part [P3a] of Proposition 3, secrecy dominates disclosure if and only if $c \in [1, 1.8]$. If $c \in [1.8, 2.28]$ then under secrecy both $(1, 1; 1, 1)$ and $(0, 0; 0, 0)$ are NE, and if $c \in [2.28, 2.73]$ then $(1, 1; 1, 1)$, $(0, 0; 1, 1)$ and $(0, 0; 0, 0)$ are all NE. Thus the range of c over which secrecy dominates disclosure shrinks due to the additional constraint in (14), and the intermediate range with ambiguous ranking expands from $c \in [2.28, 2.73]$ to $c \in [1.8, 2.73]$. With a lower value of α , non-observability of efforts has thrown in the additional shirking equilibrium.

We have thus shown that as α is varied, although regions of c values exhibiting particular types of dominance may be affected (which is expected), our basic hypothesis about the double-edged nature of transparency remains validated even when efforts are not observable. One can provide similar illustrations for different values of β . □

5. Conclusion

Often failure of important decisions is attributed to lack of transparency of procedures or relevant information. Or if one wants to avert criticisms for failures, giving the defense of having followed a transparent procedure is not uncommon. Much of the skepticism about transparency so far have been directed at political applications. This paper extends the analysis to team problems. The message is a mixed one – transparency can be good or bad depending on specific environment. This suggests that perhaps decision makers should be left to their own discretion on procedural matters.

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Appendix A

Proof of Lemma 2. [L2a] For $\mathbf{e}_1 = (1, 1)$, the continuation game (summarized in Fig. 4) simplifies to Fig. 6.

First, note that $\mathbf{e}_{\mathcal{G}_{(1,1)}^S}^* = (1, 1)$ if and only if

$$\begin{aligned} \beta(\beta v - c) + (1 - \beta)(\beta^2 v - c) &\geq \beta(\alpha v) + (1 - \beta)\alpha\beta v \\ \text{i.e. } \beta(\beta - \alpha)(2 - \beta)v &\geq c. \end{aligned} \tag{A.1}$$

Each player's expected payoff from the first-round strategy profile $(1, 1)$ (followed by $(1, 1)$ in the second round) is

$$\begin{aligned} Eu_{11}^S(1, 1; 1, 1) = Eu_{21}^S(1, 1; 1, 1) &= \beta^2 v + \beta(1 - \beta)\beta v \\ &+ (1 - \beta)\beta(\beta v - c) + (1 - \beta)^2(\beta^2 v - c). \end{aligned}$$

Now suppose that player 2 deviates to $\mathbf{e}_{21} = 0$. By Corollary 1, $(1, 1)$ is an NE in the continuation game $\mathcal{G}_{(1,0)}^S$. Then player 2's expected payoff from the first-round strategy profile $(1, 0)$ (followed by $(1, 1)$ in the second round) is

$$\begin{aligned} Eu_{21}^S(1, 0; 1, 1) &= \alpha\beta v + \beta(1 - \alpha)(\beta v - c) + (1 - \beta)\alpha(\beta v) \\ &+ (1 - \beta)(1 - \alpha)(\beta^2 v - c). \end{aligned}$$

Thus,

$$\begin{aligned} Eu_{21}^S(1, 1; 1, 1) - Eu_{21}^S(1, 0; 1, 1) &= (\beta - \alpha)\beta v + (\beta - \alpha)(1 - \beta)\beta v - (\beta - \alpha)\beta(\beta v - c) \\ &- (\beta - \alpha)(1 - \beta)(\beta^2 v - c) - c \\ &= (\beta - \alpha)[(2 - \beta)\beta v - (2 - \beta)\beta^2 v + c] - c \\ &= (\beta - \alpha)[(2 - \beta)(1 - \beta)\beta v + c] - c \\ &= (\beta - \alpha)(2 - \beta)(1 - \beta)\beta v + (\beta - \alpha)c - c, \end{aligned}$$

and the deviation is unprofitable, i.e., $Eu_{21}^S(1, 1; 1, 1) \geq Eu_{21}^S(1, 0; 1, 1)$, if and only if

$$\frac{\beta(\beta - \alpha)(2 - \beta)(1 - \beta)}{1 - (\beta - \alpha)}v \geq c. \tag{A.2}$$

Therefore, $(1, 1; 1, 1)$ is an SPE with secrecy if and only if (A.1) and (A.2) hold, i.e.,

$$\begin{aligned} c &\leq \min\left\{\beta(\beta - \alpha)(2 - \beta)v, \left[\frac{(1 - \beta)}{1 - (\beta - \alpha)}\right]\beta(\beta - \alpha)(2 - \beta)v\right\} \\ &= \frac{\beta(\beta - \alpha)(2 - \beta)(1 - \beta)}{1 - (\beta - \alpha)}v. \end{aligned}$$

[L2b] By Corollary 1, $\mathbf{e}_{\mathcal{G}_{(1,1)}^S}^* = (1, 1)$. In fact, a stronger claim is that $\mathbf{e}_{\mathcal{G}_{(1,1)}^S}^* = (1, 1)$ is also a unique “strict dominant strategy” equilibrium

		P2	
		0	1
P1	0	$\beta(\alpha v) + (1 - \beta)(\alpha^2 v),$ $\beta(\alpha v) + (1 - \beta)(\alpha^2 v)$	$\beta(\alpha v) + (1 - \beta)(\alpha \beta v),$ $\beta(\beta v - c) + (1 - \beta)(\alpha \beta v - c)$
	1	$\beta(\beta v - c) + (1 - \beta)(\alpha \beta v - c),$ $\beta(\alpha v) + (1 - \beta)(\alpha \beta v)$	$\beta(\beta v - c) + (1 - \beta)(\beta^2 v - c),$ $\beta(\beta v - c) + (1 - \beta)(\beta^2 v - c)$

Fig. 6. Simultaneous-move game $\mathcal{G}_{(1,1)}^S$.

(see footnote 14 for the nature of the game being considered). To see this, note that in the continuation game $\mathcal{G}_{(1,1)}^S$, exerting effort instead of shirking yields each player a strictly higher payoff whether his partner shirks or exerts effort (refer to Fig. 6):

$$\beta(\beta v - c) + (1 - \beta)(\alpha \beta v - c) - (\beta(\alpha v) + (1 - \beta)\alpha^2 v) = \beta(\beta - \alpha)v - c + (1 - \beta)\alpha(\beta - \alpha)v > 0,$$

and

$$\beta(\beta v - c) + (1 - \beta)(\beta^2 v - c) - \beta(\alpha v) - (1 - \beta)\alpha \beta v = \beta[(\beta - \alpha)v - c] + (1 - \beta)[\beta(\beta - \alpha)v - c] > 0.$$

Both inequalities follow from condition (2). Therefore, both players exerting effort is the unique strict dominant strategy equilibrium.

□

Proof of Lemma 3. For $e_1 = (0, 0)$, the continuation game (summarized in Fig. 4) simplifies to Fig. 7.

By Corollary 1, (1, 1) is an NE of this continuation game. Player 1's expected payoff when the players choose (0, 0) in Round 1 followed by (1, 1) in Round 2, is

$$Eu_{11}^S(0, 0; 1, 1) = \alpha^2 v + \alpha(1 - \alpha)\beta v + (1 - \alpha)\alpha(\beta v - c) + (1 - \alpha)^2(\beta^2 v - c).$$

Suppose that player 1 deviates to $e_{11} = 1$. By Corollary 1, $e_{(1,0)}^* = (1, 1)$. We then see that this deviation results in an expected payoff of

$$Eu_{11}^S(1, 0; 1, 1) = \alpha \beta v + \beta(1 - \alpha)\beta v + (1 - \beta)\alpha(\beta v - c) + (1 - \beta)(1 - \alpha)(\beta^2 v - c) - c,$$

and the deviation is unprofitable if and only if

$$Eu_{11}^S(1, 0; 1, 1) - Eu_{11}^S(0, 0; 1, 1) = (\beta - \alpha)[\alpha v + (1 - \alpha)\beta v - \alpha \beta v - (1 - \alpha)\beta^2 v + c] - c = (\beta - \alpha)[(1 - \beta)\alpha v + (1 - \alpha)(1 - \beta)\beta v + c] - c \leq 0,$$

that is, for given β, v , and α ,

$$\frac{(\beta - \alpha)[\beta + \alpha(1 - \beta)](1 - \beta)}{1 - (\beta - \alpha)} v \leq c.$$

Therefore, (0, 0; 1, 1) is an SPE with secrecy if and only if

$$\frac{(\beta - \alpha)[\beta + \alpha(1 - \beta)](1 - \beta)}{1 - (\beta - \alpha)} v \leq c. \quad \square$$

Proof of Proposition 1. [P1a] Recall that $(1, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$ will be an MPE under the policy of disclosure if and only if the cost parameter c satisfies (1) and (2), and (5). The first two conditions are summarized in (9). If (10) holds, then (5) is satisfied, since

$$\begin{aligned} & \frac{(\beta - \alpha)[\beta + \alpha(1 - \beta)](1 - \beta)}{1 - (\beta - \alpha)} v < (\beta - \alpha)g(\alpha, \beta)v: \\ & (\beta - \alpha)g(\alpha, \beta)v - \frac{(\beta - \alpha)[\beta + \alpha(1 - \beta)](1 - \beta)}{1 - (\beta - \alpha)} v \\ & = \frac{(\beta - \alpha)(2\beta - \alpha^2)(1 - \beta)}{1 - \beta(\beta - \alpha)} v - \frac{(\beta - \alpha)[\beta + \alpha(1 - \beta)](1 - \beta)}{1 - (\beta - \alpha)} v \\ & = \left[\frac{2\beta - \alpha^2}{1 - \beta(\beta - \alpha)} - \frac{\beta + \alpha(1 - \beta)}{1 - (\beta - \alpha)} \right] (\beta - \alpha)(1 - \beta)v \\ & = \left[\frac{(2\beta - \alpha^2)[1 - (\beta - \alpha)] - [\beta + \alpha(1 - \beta)][1 - \beta(\beta - \alpha)]}{[1 - \beta(\beta - \alpha)][1 - (\beta - \alpha)]} \right] (\beta - \alpha)(1 - \beta)v \\ & = \left[\frac{(2\beta - \alpha^2) - (\beta - \alpha)(2\beta - \alpha^2) - [\beta + \alpha(1 - \beta)] + \beta(\beta - \alpha)[\beta + \alpha(1 - \beta)]}{[1 - \beta(\beta - \alpha)][1 - (\beta - \alpha)]} \right] (\beta - \alpha)(1 - \beta)v \\ & = \left[\frac{2\beta - \alpha^2 - \beta - \alpha + \alpha\beta + (\beta - \alpha)[\beta^2 + \alpha\beta - \alpha\beta^2 - 2\beta + \alpha^2]}{[1 - \beta(\beta - \alpha)][1 - (\beta - \alpha)]} \right] (\beta - \alpha)(1 - \beta)v \\ & = \left[\frac{\beta - \alpha^2 - \alpha + \alpha\beta + (\beta - \alpha)[\beta^2 + \alpha\beta - \alpha\beta^2 - 2\beta + \alpha^2]}{[1 - \beta(\beta - \alpha)][1 - (\beta - \alpha)]} \right] (\beta - \alpha)(1 - \beta)v \\ & = \left[\frac{(\beta - \alpha) + \alpha(\beta - \alpha) + (\beta - \alpha)[\beta^2 + \alpha\beta - \alpha\beta^2 - 2\beta + \alpha^2]}{[1 - \beta(\beta - \alpha)][1 - (\beta - \alpha)]} \right] (\beta - \alpha)(1 - \beta)v \\ & = \left[\frac{(\beta - \alpha)[1 - 2\beta + \beta^2 + \alpha + \alpha^2 + \alpha\beta - \alpha\beta^2]}{[1 - \beta(\beta - \alpha)][1 - (\beta - \alpha)]} \right] (\beta - \alpha)(1 - \beta)v \\ & = \left[\frac{(\beta - \alpha)[(1 - \beta)^2 + \alpha(1 + \alpha) + \alpha\beta(1 - \beta)]}{[1 - \beta(\beta - \alpha)][1 - (\beta - \alpha)]} \right] (\beta - \alpha)(1 - \beta)v \\ & > 0. \end{aligned}$$

Next we show that the following strategies also constitute an MPE under disclosure:

- Round 1: both players exert effort in the first round.
- Round 2: any player who fails in Round 1 will exert effort in Round 2, regardless of the other player's first-round outcome or their efforts.

		Player 2	
		0	1
Player 1	0	$\alpha(\alpha v) + (1 - \alpha)(\alpha^2 v),$ $\alpha(\alpha v) + (1 - \alpha)(\alpha^2 v)$	$\alpha(\alpha v) + (1 - \alpha)(\alpha \beta v),$ $\alpha(\beta v - c) + (1 - \alpha)(\alpha \beta v - c)$
	1	$\alpha(\beta v - c) + (1 - \alpha)(\alpha \beta v - c),$ $\alpha(\alpha v) + (1 - \alpha)(\alpha \beta v)$	$\alpha(\beta v - c) + (1 - \alpha)(\beta^2 v - c),$ $\alpha(\beta v - c) + (1 - \alpha)(\beta^2 v - c)$

Fig. 7. Simultaneous-move game $\mathcal{G}_{(0,0)}^S$.

Note that the second-round strategies, like the reinforcement strategies $\{\tilde{e}_{22}(\mathbf{a})\}$, are consistent with **Assumption 1**, except that in contrast to $\tilde{e}_{22}(\mathbf{a})$, both players now choose to coordinate on the “good equilibrium” whenever they find themselves in the one-shot game \mathcal{G} . Also, in the subgame where a player is the only one who failed, the strategy of exerting effort is sequentially rational as implied by (3).

Therefore, given that the players play in the second round subgames the NE (or sequentially rational) strategies as specified, the expected payoff of player 1 in the first-round, simultaneous-move game for each first-round effort profile (e_{11}, e_{21}) under disclosure can be written as follows:

$$Eu_{11}^{D'}(e_{11}, e_{21}) = p(e_{11})p(e_{21})v + p(e_{11})(1-p(e_{21}))\beta v + (1-p(e_{11}))p(e_{21})(\beta v - c) + (1-p(e_{11}))(1-p(e_{21}))(\beta^2 v - c) - ce_{11}.$$

Let $Eu_{11}^{D'}(1, 1) = Eu_{21}^{D'}(1, 1) = z'$ and $Eu_{11}^{D'}(0, 1) = Eu_{21}^{D'}(1, 0) = y'$:

$$z' = \beta^2 v + \beta(1-\beta)\beta v + (1-\beta)\beta(\beta v - c) + (1-\beta)(1-\beta)(\beta^2 v - c) - c,$$

$$y' = \alpha\beta v + \alpha(1-\beta)\beta v + (1-\alpha)\beta(\beta v - c) + (1-\alpha)(1-\beta)(\beta^2 v - c).$$

Therefore, in the reduced one-shot game under disclosure, $(1, 1)$ is an NE if and only if $z' \geq y'$; that is,

$$(\beta - \alpha)\beta v + (\beta - \alpha)(1 - \beta)\beta v - c \geq (\beta - \alpha)\beta(\beta v - c) + (\beta - \alpha)(1 - \beta)(\beta^2 v - c)$$

i.e.,
$$\frac{(\beta - \alpha)[(2\beta - \beta^2)(1 - \beta)]}{1 - (\beta - \alpha)} v \geq c. \tag{A.3}$$

But $\frac{(\beta - \alpha)[(2\beta - \beta^2)(1 - \beta)]}{1 - (\beta - \alpha)} v > \frac{(\beta - \alpha)\beta + \alpha(1 - \beta)(1 - \beta)}{1 - (\beta - \alpha)} v$, since $(2\beta - \beta^2) - (\beta + \alpha(1 - \beta)) = \beta - \beta^2 - \alpha(1 - \beta) = \beta(1 - \beta) - \alpha(1 - \beta) = (\beta - \alpha)(1 - \beta) > 0$. Therefore, if condition (10) holds, then (A.3) holds as well.

[P1b] First note that

$$\frac{\beta(\beta - \alpha)(2 - \beta)(1 - \beta)}{1 - (\beta - \alpha)} v > \frac{(\beta - \alpha)[\beta + \alpha(1 - \beta)](1 - \beta)}{1 - (\beta - \alpha)} v. \tag{A.4}$$

This is because

$$\begin{aligned} & \frac{\beta(\beta - \alpha)(2 - \beta)(1 - \beta)}{1 - (\beta - \alpha)} v - \frac{(\beta - \alpha)[\beta + \alpha(1 - \beta)](1 - \beta)}{1 - (\beta - \alpha)} v \\ &= (\beta(2 - \beta) - [\beta + \alpha(1 - \beta)]) \left[\frac{(\beta - \alpha)(1 - \beta)}{1 - (\beta - \alpha)} v \right] \\ &= (2\beta - \beta^2 - \beta - \alpha(1 - \beta)) \left[\frac{(\beta - \alpha)(1 - \beta)}{1 - (\beta - \alpha)} v \right] \\ &= (\beta(1 - \beta) - \alpha(1 - \beta)) \left[\frac{(\beta - \alpha)(1 - \beta)}{1 - (\beta - \alpha)} v \right] \\ &= (\beta - \alpha)(1 - \beta) \left[\frac{(\beta - \alpha)(1 - \beta)}{1 - (\beta - \alpha)} v \right] > 0. \end{aligned}$$

Therefore, if (10) holds then (7) is satisfied, and using **Lemma 2** (in particular [L2a]) we conclude that $(1, 1; 1, 1)$ is an SPE under secrecy.

Recall that none of the continuation games under secrecy have asymmetric equilibria (see Remark 2 in Section 4). Thus none of the strategy profiles $(1, 1; 1, 0)$, $(1, 1; 0, 1)$, $(1, 0; 1, 0)$, $(1, 0; 0, 1)$, $(0, 1; 1, 0)$, $(0, 1; 0, 1)$, $(0, 0; 1, 0)$, and $(0, 0; 0, 1)$ can be SPE.

Next, consider the strategy profiles $(1, 1; 0, 0)$, $(1, 0; 0, 0)$, and $(0, 1; 0, 0)$. By [L2b], $\mathbf{e}_{\mathcal{G}_{(1,1)}^S}^* \neq (0, 0)$, thus $(1, 1; 0, 0)$ cannot be an SPE. For $\mathbf{e}_1 = (1, 0)$, the continuation game originally summarized in Fig. 4 simplifies to Fig. 8.

In the continuation game $\mathcal{G}_{(1,0)}^S$, $(0, 0)$ is an NE if and only if (refer to Fig. 8):

(Player 2’s best-response)

$$\begin{aligned} \beta(\alpha v) + (1 - \beta)\alpha^2 v &\geq \beta(\beta v - c) + (1 - \beta)(\alpha\beta v - c) \\ \text{i.e. } c &\geq \beta(\beta - \alpha)v + (1 - \beta)\alpha(\beta - \alpha)v \\ \text{i.e. } c &\geq [\beta + \alpha(1 - \beta)](\beta - \alpha)v, \end{aligned}$$

which contradicts condition (2). Thus, $\mathbf{e}_{\mathcal{G}_{(1,0)}^S}^* \neq (0, 0)$ (by symmetry, $\mathbf{e}_{\mathcal{G}_{(0,1)}^S}^* \neq (0, 0)$), and the strategy profiles $(1, 0; 0, 0)$ and $(0, 1; 0, 0)$ cannot be SPE.

By Corollary 1, $\mathbf{e}_{\mathcal{G}_{(1,0)}^S}^* = (1, 1)$. To show that $(1, 0; 1, 1)$ cannot be an SPE, recall the proof of Lemma 2. Note that if condition (10) holds, then in the proof of Lemma 2, condition (A.2) is satisfied as a strict inequality (because of (A.4)), and $Eu_{21}^S(1, 1; 1, 1) > Eu_{21}^S(1, 0; 1, 1)$; that is, player 2’s payoff from the first-round strategy profile $(1, 0)$ (followed by $(1, 1)$ in the second round) is strictly less than his payoff from the first-round strategy profile $(1, 1)$ (followed by $(1, 1)$ in Round 2). Therefore, given that player 1 is choosing $e_{11} = 1$, player 2 is strictly better off deviating in Round 1 from $e_{21} = 0$ to $e_{21} = 1$, thus $(1, 0; 1, 1)$ is not an SPE.

Since $(1, 0; 1, 1)$ is not an SPE, $(0, 1; 1, 1)$ is likewise not an SPE, by symmetry.

By Lemma 3, $(0, 0; 1, 1)$ is not an SPE (because condition (10) implies violation of (8)).

Finally, suppose that following the first-round strategy profile $(0, 0)$, in the continuation game the strategy profile $(0, 0)$ is played. Then player 1’s payoff is

$$Eu_{11}^S(0, 0; 0, 0) = \alpha^2 v + \alpha(1 - \alpha)\alpha v + (1 - \alpha)\alpha^2 v + (1 - \alpha)^2 \alpha^2 v.$$

Player 1’s payoff from the first-round profile $(0, 0)$ when it is followed by $(1, 1)$ in the second round is

$$Eu_{11}^S(0, 0; 1, 1) = \alpha^2 v + \alpha(1 - \alpha)\beta v + (1 - \alpha)\alpha(\beta v - c) + (1 - \alpha)^2(\beta^2 v - c).$$

By condition (2), $\beta^2 v - c > \alpha^2 v$, and by condition (3), $\beta v - c > \alpha v$ (recall Assumption 1, or equivalently condition (9), implies (2) and (3)), so $Eu_{11}^S(0, 0; 1, 1) > Eu_{11}^S(0, 0; 0, 0)$. Condition (10) implies that $Eu_{11}^S(1, 0; 1, 1) > Eu_{11}^S(0, 0; 1, 1)$ (see the proof of Lemma 3). Therefore, $Eu_{11}^S(1, 0; 1, 1) > Eu_{11}^S(0, 0; 0, 0)$: given that player 2 chooses $e_{21} = 0$ in the first round, player 1 is strictly better off deviating to $e_{11} = 1$ in the first round, given that $(1, 1)$ is an equilibrium in the continuation game under secrecy (under Assumption 1) by Corollary 1. Therefore, $(0, 0; 0, 0)$ is not an SPE. This completes the argument that the equilibrium, $\mathbf{e}_{\mathcal{G}_1^S}^* = (1, 1; 1, 1)$, is unique. □

Proof of Proposition 2. [P2a] If conditions (11) and (13) hold, then condition (6) is satisfied and Lemma 1 applies.

[P2b] If $c \leq \beta(\beta - \alpha)v$ (see condition (11)), then the right-hand side inequality of (8) is satisfied, since $\beta(\beta - \alpha)v < (\beta - \alpha)[\beta + \alpha(1 - \beta)]v$. If condition (12) holds, then the left-hand side inequality of (8) is also satisfied, because of (A.4). So Lemma 3 applies.

[P2c] First note that condition (7) must be met for $\mathbf{e}_{\mathcal{G}_1^S}^* = (1, 1; 1, 1)$ to arise. Consequently, if (12) holds, then $\mathbf{e}_{\mathcal{G}_1^S}^* \neq (1, 1; 1, 1)$. Next, by Remark 2 in Section 4, $\mathcal{G}_{(1,1)}^S$ and $\mathcal{G}_{(1,0)}^S$ do not have any asymmetric equilibrium. Therefore, $(1, 1; 1, 0)$, $(1, 1; 0, 1)$, $(1, 0; 1, 0)$ and $(1, 0; 0, 1)$ cannot be SPE. Finally, recall that $Eu_{11}^S(1, 0; 1, 1) \leq Eu_{11}^S(0, 0; 1, 1)$ if and only if $c \geq \frac{(\beta - \alpha)\beta + \alpha(1 - \beta)(1 - \beta)}{1 - (\beta - \alpha)} v$ (with the respective strict inequalities in the two relations exactly corresponding); see the proof of Lemma 3. By (A.4), condition (12) implies that $c > \frac{(\beta - \alpha)\beta + \alpha(1 - \beta)(1 - \beta)}{1 - (\beta - \alpha)} v$. Thus, $Eu_{11}^S(1, 0; 1, 1) < Eu_{11}^S(0, 0; 1, 1)$, and $(1, 0; 1, 1)$ cannot be an SPE.

		Player 2	
		0	1
Player 1	0	$\alpha(\alpha v) + (1 - \alpha)(\alpha^2 v),$ $\beta(\alpha v) + (1 - \beta)(\alpha^2 v)$	$\alpha(\alpha v) + (1 - \alpha)(\alpha\beta v),$ $\beta(\beta v - c) + (1 - \beta)(\alpha\beta v - c)$
	1	$\alpha(\beta v - c) + (1 - \alpha)(\alpha\beta v - c),$ $\beta(\alpha v) + (1 - \beta)(\alpha\beta v)$	$\alpha(\beta v - c) + (1 - \alpha)(\beta^2 v - c),$ $\beta(\beta v - c) + (1 - \beta)(\beta^2 v - c)$

Fig. 8. Simultaneous-move game $\mathcal{G}_{(1,0)}^S$.

[P2d] We are going to show that conditions (11)–(13) would rule out disclosure equilibria that are inferior to the secrecy $SPE(0, 0; 1, 1)$. Earlier in the text (before the formal statement of the proposition), we have argued that if Assumption 1 holds, then the only strategy profiles under disclosure that are either inferior or not directly comparable with $\mathbf{e}_{\mathcal{G}_1^S}^* = (0, 0; 1, 1)$ (and that can possibly arise in equilibrium) are $(1, 0; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$, $(0, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$, and $(0, 0; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$.

The strategy profiles $(1, 0; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$ and $(0, 1; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$ cannot be MPE since these require (refer to Fig. 2):

$$y \geq z, \quad \text{i.e.,} \quad c \geq (\beta - \alpha)g(\alpha, \beta)v, \tag{A.5}$$

which is inconsistent with condition (13). On the other hand, $(0, 0; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$ is an MPE if and only if, in \mathcal{G}_1^D (refer to Fig. 2):

$$\begin{aligned} &x \geq w \\ \text{i.e.,} \quad &\alpha^2 v + \alpha(1 - \alpha)\beta v + (1 - \alpha)\alpha(\beta v - c) + (1 - \alpha)^2 \alpha^2 v \\ &\geq \beta \alpha v + \beta(1 - \alpha)\beta v + (1 - \beta)\alpha(\beta v - c) + (1 - \beta)(1 - \alpha)\alpha^2 v - c \\ \text{i.e.,} \quad &-\alpha(\beta - \alpha)v - (1 - \alpha)(\beta - \alpha)\beta v + \alpha(\beta - \alpha)(\beta v - c) + (\beta - \alpha)(1 - \alpha)\alpha^2 v + c \geq 0 \tag{A.6} \\ \text{i.e.,} \quad &c \geq \frac{(\beta - \alpha)[(2\beta - \alpha^2)(1 - \alpha) - (\beta - \alpha)]}{1 - \alpha(\beta - \alpha)}v \\ \text{i.e.,} \quad &c \geq (\beta - \alpha)h(\alpha, \beta)v, \end{aligned}$$

where $h(\alpha, \beta) = \frac{(2\beta - \alpha^2)(1 - \alpha) - (\beta - \alpha)}{1 - \alpha(\beta - \alpha)}$. However, if condition (13) holds, then (A.6) will not be met. Therefore, $(0, 0; \tilde{e}_{12}(\mathbf{a}), \tilde{e}_{22}(\mathbf{a}))$ cannot be an MPE. \square

Appendix B. Supplementary data

Supplementary data to this article can be found online at doi:10.1016/j.jpube.2011.01.009.

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