PEER TRANSPARENCY IN TEAMS: DOES IT HELP OR HINDER INCENTIVES?

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Abstract

In a joint project involving two players of a two-round effort investment game with complementary efforts, transparency, by allowing players to observe each other's efforts, achieves at least as much, and sometimes more, collective and individual efforts relative to a non-transparent environment. Without transparency multiple equilibria can arise and transparency eliminates the inferior equilibria. When full cooperation arises only under transparency, it occurs *gradually*: no worker sinks in the maximum amount of effort in the first round, preferring instead to smooth out contributions over time. If the players' efforts are substitutes, transparency makes no difference to equilibrium efforts. ***JEL* Classification:** D02; J01. **Key Words:** Transparency, team, complementarity, substitution, free-riding, weak dominance, neutrality, implementation costs.

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1 Introduction

Joint projects in teams based on voluntary contributions of efforts are vulnerable to free-riding. In formulating incentives, an organization may influence its members' effort decisions through careful design of the structure of contributions implying how much the members know about each other's efforts. This type of knowledge can be facilitated by an appropriate work environment, such as an open space work-floor or regular reporting of actual working hours. We aim to show how *transparency* in effort contributions within a team may (or may not) help to mitigate shirking and foster cooperation. Empirical evidence certainly point to the relevance of this kind of transparency as a key determinant of productive efficiency (Teasley et al., 2002; Heywood and Jirjahn, 2004; Falk and Ichino, 2006).

When efforts are observable during a project's live phase (i.e., in a transparent environment), team members play a *repeated contribution game*. On the other hand, when efforts cannot be observed (i.e., a non-transparent environment), the project is a *simultaneous move game*. The repeated contribution game expands the players' strategy sets relative to a simultaneous move game because later period actions can be conditioned on the history. The additional strategies 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. By enlarging or shrinking the equilibrium set or by simply altering it, does observability of interim efforts induce more overall efforts or less efforts? Which game form is better? With this being the focal point of our query, we will explore the relationships between transparency, team production technology and incentives.

In teams, repeated games and dynamic public good settings, the general issue of transparency (i.e., observability/disclosure of actions) and its incentive implications have been studied by several authors. See Che and Yoo (2001), Lockwood and Thomas (2002), Andreoni and Samuelson (2006) etc. in the context of dynamic/repeated games, Mohnen et al. (2008), and Winter (2010) in the context of repeated and sequential contribution team projects, and Admati and Perry (1991), Marx and Matthews (2000) etc. in dynamic voluntary contribution pure public good settings.[1]

Our paper is closer to the peer transparency problems of Mohnen et al. (2008) and Winter (2010). Mohnen et al. consider a team of two workers exerting efforts over two rounds, with the total output equaling the sum of efforts by the workers (i.e., the technology is one of perfect substitutes). The workers are paid identical remunerations – a fixed wage plus bonus – with the latter being a positive fraction of the team output. When the workers are averse to inequality of efforts, allowing the contribution game to be transparent by making each other's first-round efforts observable improves the overall contribution and output relative to when the workers cannot observe the first-round efforts. Further, if the workers' utility functions are modified by dropping the inequity aversion component, then transparency makes no difference to the equilibrium efforts and output. Thus in their model the benefits of transparency are realized largely due to the workers' distaste for inequity.

In the context of a team project, Winter (2010) asks when more information among peers about each other's efforts (*IIE* or 'internal information about effort' measuring transparency)

[1]Some of the other works on strategic disclosure (or non-disclosure) of information about peers include: workers' ability differentiation through incentive/uniform wage contracts (Fang and Moscarini, 2005), outsiders learning about experts' ability through individual votes cast in committee decisions (Levy, 2007), how cheap-talk undermines transparency of contributions in discrete public good games (Agastya, 2009), etc. In a related paper (Bag and Pepito, 2011), we consider a team problem consisting of multiple tasks with strong complementarities and where the team members assigned to different tasks make multiple attempts to succeed. Our main concern there is whether the project manager should disclose interim *outcomes* of tasks to motivate efforts. We show that commitment to disclose outcomes has countervailing implications: a team member's success encourages another to exert efforts, whereas failure dampens effort incentives.

There is also a parallel literature on tournaments (Lizzeri et al. (2003), Gershkov and Perry (2009), Aoyagi (2010), etc.), where the focus is on interim performance evaluations (or feedbacks) to incentivize player efforts. Transparency in teams is very different from feedbacks for two reasons: (i) because of the public good nature of the players' rewards, in contrast to tournaments where the reward is of the winner-take-all variety; (ii) interim efforts do not directly translate into rewards whereas in tournaments rewards are a function of interim performance.

makes it easier for the principal to provide incentives so that all agents exert "effort" (called the *INI* outcome).[2] The agents can either exert effort or shirk as a one-off effort investment decision, and each agent's effort choice is made at different points of time although an agent may or may not observe the past decisions by the earlier agents. With an acyclic binary order, k, on the agents reflecting an *IIE*,[3] if any two *IIE*s, say k_1 and k_2, can be compared in the manner k_1 is "richer" than k_2,[4] then k_1 is said to be more transparent than k_2. Then, defining a project to exhibit complementarity (substitution) if an agent's effort is marginally more (less) effective in improving the project's probability of success as the set of other agents who also exert effort expands, the paper makes several interesting observations: (i) if a project satisfies complementarity, then it is less costly to induce *INI* the more transparent the *IIE*; (ii) a sequential architecture in which each agent observes his immediate predecessor's effort is the most transparent *IIE*; and (iii) if the project exhibits substitution, transparency is no longer important, i.e., neutral, in inducing *INI*; etc.

We complement and extend the analysis of Mohnen et al. (2008) and Winter (2010), by studying a team setting with some plausible and important model features not considered by these authors. There is a project consisting of two tasks. Two workers work over two rounds on one task each, and in each round a worker may choose to put in zero, one or two units of effort with total efforts over two rounds not exceeding two units. The project outcome materializes only at the end of the second round. The project's success probability is increasing in the total efforts invested in each task. The project exhibits complementarity (substitutability) if the incremental success probability due to additional efforts in a task

[2] Winter (2006) analyzes the problem of incentive provision in a team where its members exert efforts sequentially towards a joint project, whereas Winter (2004) studies another team problem where the agents move simultaneously. On incentive design with complementarities across tasks but in a principal-agent setting (rather than team setting), see MacDonald and Marx (2001).

[3] An ordering of peers in the form of $i_1\ k\ i_2\ k...k\ i_r$ indicates that peer i_1 knows peer i_2's effort, i_2 knows i_3's effort, and so on.

[4] I.e., $i\ k_2\ j$ would imply $i\ k_1\ j$ but not necessarily the other way around.

is increasing (decreasing) in the efforts invested in the other task. Each worker receives a common reward $v > 0$ if the project is successful and receives zero otherwise; rewards cannot be conditioned on efforts as the latter might not be verifiable. Two alternative work environments are considered: in a *transparent* (or open-floor) environment first-round efforts are publicly observed by each worker before each chooses respective second-round efforts; in a *non-transparent* (or closed-door) environment efforts are not observed.

Among the modeling differences, ours consider more general technologies than the one analyzed by Mohnen et al. (general complementary/substitution technologies vs. perfect substitution technology) but the workers' preferences are standard utilitarian without any concern for equity. Different from Winter (2010), we allow for *repeated efforts* by the players (i.e., workers) and thus transparency in our setting not only allows a player to influence another player's future play through his own action today but also by conveying his likely actions/response the next round.[5] This intertemporal coordination in players' actions through public observation of both players' past actions demands more complicated strategic considerations compared to the one-off effort investment decision model of Winter. So the relationships between transparency, technologies and incentive provision need further scrutiny.

We show the following results. Under complementary technology, with player rewards *exogenous*, the transparent environment is weakly better than the non-transparent environment (Propositions 2 and 3) in the following sense: the best Nash equilibrium efforts pair in the non-transparent environment entailing partial or full cooperation by the players can be *uniquely* implemented in subgame-perfect equilibrium in the transparent environment, by eliminating any other inferior Nash equilibrium; in addition, we show that when shirking (i.e., $(0, 0)$) is the unique Nash equilibrium, under certain conditions the maximal efforts equilibrium or some form of cooperation (i.e., $(2, 2)$ or $(2, 1)$) can be achieved with trans-

[5]In Winter (2010), the structure of *IIE* rules out mutual knowledge of efforts as there is a fixed timing structure according to which the agents make their investment decisions.

parency. Further, when full cooperation is induced only under observability of efforts, it involves each worker putting in one unit of effort in the first round followed by another unit of effort in the second round. Thus, full cooperation might be achieved at best *gradually* – transparency allows workers to make observable partial commitments in the first round and complete the project successfully by supplying the remaining efforts in the second round (Proposition 2).[6,7] Based on the weak-dominance result in Proposition 3 we further show that when the principal determines the rewards *optimally*, compared to non-transparency the principal can achieve weak or unique implementation of full cooperation at no more and possibly lower overall costs in a transparent environment (Proposition 4). All these results are derived assuming symmetric players, but it should also become clear that the related intuitions are applicable more generally; see Proposition 5 and the discussion in section 3.5. Finally, we show that if the technology exhibits substitutability in efforts and effort costs are linear, transparency is *neutral* in terms of equilibrium efforts induced (Propositions 6 and 7).[8]

The weak-dominance property of transparency in our setup, while similar to the main theoretical result of Mohnen et al., is due to different underlying reasons. First, as our results show, the workers' inequity aversion is not necessary for explaining why organizations may favor transparency; in our setup the dominance (of transparency) obtains mainly due to the complementary nature of the production technology.[9] This enriches the possibilities under

[6]Besides a number of papers mentioned earlier, some of the other works on gradualism are Bagnoli and Lipman (1989), Fershtman and Nitzan (1991), and Gale (2001).

[7]These results we obtain assuming effort costs are linear. For increasing marginal costs, both weak-dominance and gradualism hold but the uniqueness of equilibrium involving partial or full cooperation may not be guaranteed under transparency.

[8]Elsewhere Pepito (2010) has shown that for increasing marginal costs of effort, transparency is *harmful*.

[9]Knez and Simester (2001) and Gould and Winter (2009) document the positive impact of peer efforts due to complementarity between team members' roles – the former is a case study on the performance of Continental Airlines in 1995, and the latter is a panel data analysis of the performance of baseball players. Gould and Winter also show negative peer effect when the players are substitutes.

which organizations may favor a transparent work arrangement beyond the environment studied by Mohnen et al. The contrast between complementary and substitution technologies with their differing implications (for transparency) is similar to Winter's (2010) result. But unlike in Winter's paper the players in our setting receive identical rewards, so there is no discrimination among team members (according to one's position in the sequential efforts chain).

Another point may be noted here. In a public good setting with perfect substitutability in contributions, Varian (1994) made the observation that if agents contribute sequentially, rather than simultaneously, the free-riding problem gets worse – total contribution in a sequential move game is never more and possibly less than in a simultaneous move game.[10] As Winter (2010) has shown, if an external authority can give discriminatory rewards to the contributors of a joint project, then even though such projects exhibit public good features, sequential game performs better than a simultaneous move game when player efforts are complementary. And we show that, in joint projects, the domination over the simultaneous move format can be extended to the repeated contributions format. So unlike in the sequential move game of Varian, observability of contributions is distinctly a positive aspect for complementary production technology.

The model is presented next. In sections 3 and 4, we derive our main results on transparency. Section 5 concludes. Proofs of the main results are in Appendix **A**. A supplementary materials section available online contains omitted proofs and additional results.

2 The Model

A team of two identical risk-neutral members, henceforth players, engage in a joint project involving two tasks, with one player responsible for one task each. The probability of the

[10] Bag and Roy (2008) show that if agents contribute repeatedly to a public good and have incomplete information about each other's valuations, expected total contribution may be higher relative to a simultaneous contribution game.

project's success depends on the players' aggregate effort profile over a horizon of two rounds.

In each round, players simultaneously decide on how much effort to put in. Denote player i's ($i = 1, 2$) sequence of effort choices by $\{e_{it}\}_{t=1}^{2}$, and his overall effort $e_{i1} + e_{i2}$ by $e_i \in \mathbf{E_i} = \{0, 1, 2\}$. Let $p(e_i, e_j)$ be the project's success probability. The cost to player i of performing his task is c per unit of effort, $c > 0$. If the project succeeds, both players receive a common reward $v > 0$; otherwise, they receive nothing. The payoff to player i $(= 1, 2)$, given his overall effort e_i and player j's overall effort e_j ($j \neq i, j = 1, 2$), is:

$$u_i(e_i, e_j) = p(e_i, e_j)v - ce_i. \tag{1}$$

The efforts are irreversible: shirking by player i ($e_i = 0$) means $\{e_{it}\}_{t=1}^{2} = \{0, 0\}$, partial cooperation by player i ($e_i = 1$) means either $\{e_{it}\}_{t=1}^{2} = \{1, 0\}$ or $\{e_{it}\}_{t=1}^{2} = \{0, 1\}$, and full cooperation by player i ($e_i = 2$) implies any of the following: $\{e_{it}\}_{t=1}^{2} = \{2, 0\}$, $\{e_{it}\}_{t=1}^{2} = \{0, 2\}$, or $\{e_{it}\}_{t=1}^{2} = \{1, 1\}$. So a player can choose full cooperation either by making a single contribution of two units of effort early or late in the game or by contributing *gradually*, one unit of effort in each round.

The success probability function $p(e_i, e_j)$ has the following properties:

A1. $p(2, 2) = 1$ and $p(0, 0) > 0$;

A2. *Symmetry*: $p(e_i, e_j) = p(e_j, e_i)$; and

A3. *Monotonicity*: For given e_j, $p(e_i, e_j)$ is (strictly) increasing in e_i.

The above three properties will be maintained throughout the paper. We specify a fourth property to define complementary technology, our main focus in section 3:

A4. *General Complementarity*: For any $e_j \in \{0, 1\}$, $p(1, e'_j) - p(0, e'_j) > p(1, e_j) - p(0, e_j)$ and $p(2, e'_j) - p(1, e'_j) > p(2, e_j) - p(1, e_j)$, where $e'_j > e_j$.

So, while the project succeeds for certain if and only if both players exert the maximum amount of effort, there is still some chance of success if players shirk or cooperate only partially. We have specified complementarity in a general form, requiring only that any additional effort by player i is more effective (in terms of incremental probability of success) the more cooperative player j is.[11] This formulation admits perfectly complementary technology, $p(e_i, e_j) = p(e_i)p(e_j)$, where $p(e_i)$ and $p(e_j)$ are the individual tasks' success probabilities. Also note that symmetry and monotonicity are very natural and weak assumptions; further, for complementary technology, we do not require any further curvature restriction on the success probability function: $p(.,.)$ can be concave or convex in each effort component (i.e., incremental probability of success is decreasing or increasing).[12]

Finally, v can be interpreted in two ways – as the players' valuation for the project, or their compensation as set by a principal, with v being common knowledge. The principal can condition the rewards only on the outcome and not directly on the efforts; in fact, the principal need not necessarily observe the efforts. Since players are identical, $v_1 = v_2 = v$. The paper's main insights do not depend on the identical players assumption. Most of the analysis will be carried out assuming v to be exogenous. Later on v will be solved to minimize the principal's costs of inducing full (or partial) cooperation.

We will consider two effort investment games. In one version, players are able to observe first-round effort choices in an interim stage before making second-round effort decisions, while in the other version players are unable to observe first-round actions. Observability of efforts (or the lack of it) may be due to the principal designing a suitable work environment or because of direct reporting. Following others studying similar environments, we term the observable effort case *transparent* and the one with non-observable actions *non-transparent.*

Most of our analysis in this paper will be carried out under the assumptions of constant per-unit cost of effort and symmetric players, as specified above. Towards the end of section

[11]The incremental gain (in probability of success) from own effort is assumed to be *strictly* increasing in the other player's effort, to eliminate equilibrium involving asymmetric efforts under non-transparency. A similar assumption will be made for the substitution technology in section 4 for consistency in modeling.

[12]However, in section 4 with players' efforts acting as perfect substitutes, the success probability function will be strictly concave. See footnote 21.

3 we address, separately, how changing to increasing marginal costs (of effort) might alter the results and the case of non-identical players.

3 Benefit of Transparency: Complementary Efforts

3.1 *Unobservable contributions.*

In the non-transparent environment, the players' overall efforts are determined by the Nash equilibrium (or *NE*) of the following simultaneous move game:

		Player 2		
		0	1	2
	0	$p(0,0)v, p(0,0)v$	$p(0,1)v, p(0,1)v - c$	$p(0,2)v, p(0,2)v - 2c$
Player 1	1	$p(1,0)v - c, p(1,0)v$	$p(1,1)v - c, p(1,1)v - c$	$p(1,2)v - c, p(1,2)v - 2c$
	2	$p(2,0)v - 2c, p(2,0)v$	$p(2,1)v - 2c, p(2,1)v - c$	$v - 2c, v - 2c$

Figure 1: Simultaneous move game $\mathcal{G}_N$

Denote this one-shot game by $\mathcal{G}_N$, any pure strategy profile (e_1, e_2) of $\mathcal{G}_N$ by $\mathbf{e}_N$, and any pure strategy *NE*, (e_1^*, e_2^*) of $\mathcal{G}_N$, by $\mathbf{e}_N^*$. Also, denote the *set* of pure strategy *NE* of $\mathcal{G}_N$ by $\mathcal{E}_N$.

Lemma 1. *With effort complementarities, the game $\mathcal{G}_N$ has no asymmetric pure strategy Nash equilibrium.*

The intuition derives from the fact that a player's marginal benefit from effort is increasing in the other player's effort. This means, if $(1, 0)$ is an *NE* so that putting in one unit of effort is (weakly) better than putting in zero effort for player 1, the same comparison holds true strictly for player 2 given that player 1 puts in one unit of effort. Thus, player 2 should like to deviate and $(1, 0)$ cannot be an *NE*. The same intuition applies for other asymmetric strategies.

In view of Lemma 1, in the one-shot game we focus on symmetric pure strategy equilibrium:

Proposition 1 (**One-shot Nash equilibrium**). *Assume complementary technology. In the one-shot game $\mathcal{G}_N$ (i.e., with unobservable contributions), the pure strategy Nash equilibrium (or equilibria) can be characterized as follows:*

- $(0,0) \in \mathcal{E}_N$ *if and only if*

$$c \geq \max\{(p(1,0) - p(0,0))v, [(p(2,0) - p(0,0))v]/2\};$$

- $(1,1) \in \mathcal{E}_N$ *if and only if*

$$(p(2,1) - p(1,1))v \leq c \leq (p(1,1) - p(0,1))v;$$

- $(2,2) \in \mathcal{E}_N$ *if and only if*

$$c \leq \min\{(1 - p(1,2))v, [(1 - p(0,2))v]/2\}.$$

Note that the above is a characterization result. In supplementary materials we show that *there always exists a pure strategy Nash equilibrium.* It follows therefore that there are no "gaps", and there may even be some overlaps in the equilibrium ranges of c (i.e., for given $p(\cdot,\cdot)$ and v, certain values of c yield multiple equilibria).

3.2 *Observable contributions.*

The effort investment game proceeds as follows:
Round 1: Players simultaneously choose their efforts $e_{i1} \in \mathbf{E_{i1}} = \{0, 1, 2\}$, $i = 1, 2$.
Interim period: Players' first-round decisions are revealed. Denote the set of possible observed effort levels $\mathbf{e_1} = (e_{11}, e_{21})$ by $\mathcal{H}$, so

$$\mathcal{H} = \{(0,0), (0,1), (0,2), (1,0), (1,1), (1,2), (2,0), (2,1), (2,2)\}.$$

Round 2: Players make their effort decisions simultaneously, having observed each other's first-round effort choices. Denote player i's set of admissible second-round effort choices by $\mathbf{E_{i2}}$. Since overall effort e_i cannot exceed 2,

$$\mathbf{E_{i2}} = \begin{cases} \{0,1,2\} & \text{if } e_{i1} = 0; \\ \{0,1\} & \text{if } e_{i1} = 1; \\ \{0\} & \text{if } e_{i1} = 2. \end{cases} \tag{2}$$

At the end of Round 2, the project concludes. Both players receive reward v if the project is successful. If the project fails, they both receive 0. ||

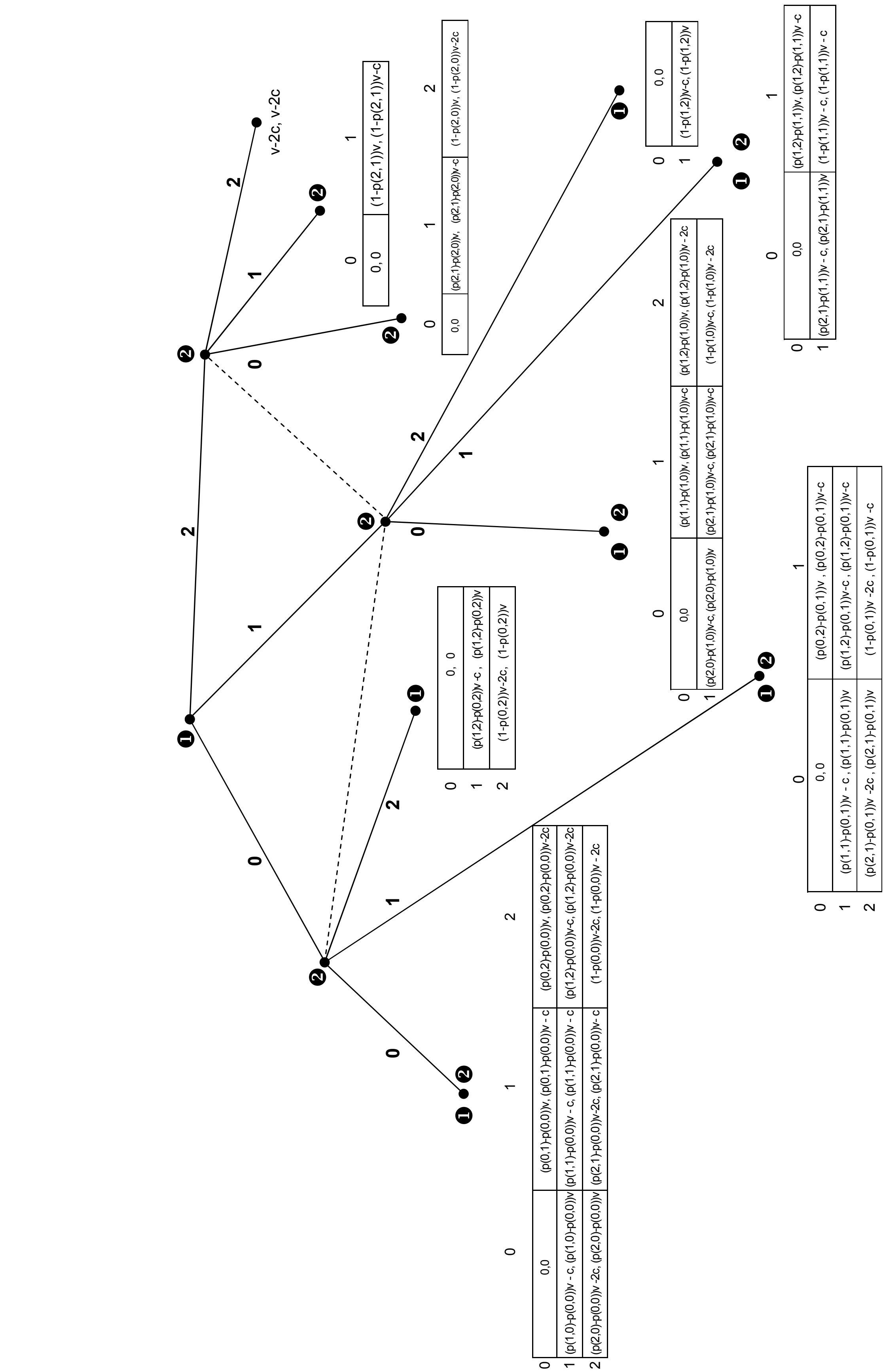

Figure 2: Extensive-form game $\mathcal{G}_T$

With observability, the joint project induces an imperfect information, repeated contribution game in which players move simultaneously in each round. This belongs to a class of games known as *multi-stage games with observed actions*, as in Fudenberg and Tirole (1991). The extensive form, denoted by $\mathcal{G}_T$, appears in Figure 2.

The payoffs in each continuation game of $\mathcal{G}_T$ are in terms of the second-round *incremental* gains relative to those yielded by the pair of first-round observed effort levels, $\mathbf{e_1}$. For example, suppose that both players choose one unit of effort in the first round. This restricts the set of admissible actions for players 1 and 2 to $\mathbf{E_{12}} = \mathbf{E_{22}} = \{0, 1\}$, resulting in a continuation game with the strategy space $\mathcal{S}_2 = \{0, 1\} \times \{0, 1\}$. (In general, the strategy space of any continuation game is $\mathcal{S}_2 = \mathbf{E_{12}} \times \mathbf{E_{22}}$.) Denote player i's *interim* payoff, i.e., payoff generated by observed effort levels $\mathbf{e_1} = (e_{11}, e_{21})$, by $\hat{u}_{i1}(e_{i1}, e_{j1})$,[13] and incremental gains following second-round actions (e_{i2}, e_{j2}) by $\hat{u}_{i2}(e_{i2}, e_{j2}|\mathbf{e_1}) = u_i(e_{i1}+e_{i2}, e_{j1}+e_{j2}) - \hat{u}_{i1}(e_{i1}, e_{j1})$.

Therefore, player i's payoffs in the continuation game following $\mathbf{e_1} = (1, 1)$ are

$$\hat{u}_{i2}(e_{i2}, e_{j2}|(1,1)) = \begin{cases} 0 & \text{if } e_{i2} = 0, e_{j2} = 0; \\ (p(1,2) - p(1,1))v & \text{if } e_{i2} = 0, e_{j2} = 1; \\ (p(2,1) - p(1,1))v - c & \text{if } e_{i2} = 1, e_{j2} = 0; \\ (1 - p(1,1))v - c & \text{if } e_{i2} = 1, e_{j2} = 1. \end{cases}$$

Payoffs for the other continuation games are computed in the same way.

One specific continuation game is worth noting here – the game following $(0, 0)$ efforts in the first round – which is same as the one-shot game $\mathcal{G}_N$ except that all the payoffs are subtracted by $p(0, 0)v$. For later use, we treat these two games to be *identical*, given that the players' strategic decisions will be the same.

Equilibrium of $\mathcal{G}_T$*.* Corresponding to $\mathcal{G}_T$, any pure strategy subgame-perfect equilibrium (or *SPE*) will be denoted by $(e^*_{11}, e^*_{21}; e^*_{12}(e^*_{11}, e^*_{21}), e^*_{22}(e^*_{11}, e^*_{21}))$, or in short, $\mathbf{e}^*_T$. To be precise, equilibrium second-round strategies should be more general functions of any first-round effort decisions and not just of (e^*_{11}, e^*_{21}). To establish a particular strategy profile as *SPE*, we will verify the Nash equilibrium property both along the equilibrium path and also following ***unilateral*** first-round deviations by either player (i.e., in the continuation games following (e_{11}, e^*_{21}) and (e^*_{11}, e_{21}), where $e_{11} \neq e^*_{11}$ and $e_{21} \neq e^*_{21}$).[14] The verification of Nash equilibrium

[13]Interim payoffs are calculated assuming as if the players will exert no further effort in Round 2.

[14]We need to check a player's deviation incentive only *one at a time*, rather than consecutive deviations

following joint deviations in the first round will not be necessary unless the players' strategies for the particular subgames are explicitly described in the strategy profile. Note that *not* specifying the continuation strategies in joint deviation subgames is not a serious omission as one can always specify a profile of Nash equilibrium strategies (which always exist for our games) appropriate for the subgame. $||$

Corresponding to $\mathbf{e}_T^*$, the aggregate effort profile is $(e_{11}^* + e_{12}^*, e_{21}^* + e_{22}^*)$. Denote the *set* of equilibrium aggregate effort profiles of $\mathcal{G}_T$ by $\mathcal{E}_T$.

Given the extensive-form representation in Figure 2, we now want to evaluate how the overall equilibrium efforts will change when efforts are made transparent. In particular, take an equilibrium (or equilibria) that arises in the one-shot game; from Proposition 1 we see that this equilibrium (or equilibria) results if and only if certain conditions hold. Taking these conditions as given, we then examine the setting with repeated, observable contributions, and determine which overall efforts result (or do not result) in an *SPE* under these conditions. Detailed characterization of the various equilibria under transparency and their comparison with the equilibria under non-transparency appear in supplementary materials.

Below we present one special type of equilibrium under observability to show how transparency can sometimes be critical to achieving full cooperation and ensuring the project's success.

PROPOSITION 2 (**Gradualism: necessary and sufficient conditions**). *Suppose a joint project satisfies general complementarity.*

[*a*] (*i*) *If* $(2,2) \notin \mathcal{E}_N$, *then the only way* $(2,2) \in \mathcal{E}_T$ *is through* ***gradualism***, *i.e.,* $(e_{11}^*, e_{21}^*; e_{12}^*, e_{22}^*) = (1,1;1,1)$.

(*ii*) $(2,2) \in \mathcal{E}_T \setminus \mathcal{E}_N$ *only when* $\mathcal{E}_N = \{(0,0)\}$.

[*b*] *Suppose* $\mathcal{E}_N = \{(0,0)\}$, *which occurs if and only if*

$$\begin{aligned} p(0,0)v &\geq \max\{p(1,0)v - c, p(2,0)v - 2c\}, \\ p(1,1)v - c &< p(0,1)v, \\ \text{and} \qquad v - 2c &< \max\{p(0,2)v, p(1,2)v - c\}. \end{aligned}$$

in the first and the second round, due to the 'one-stage deviation principle for finite-horizon games' of Fudenberg and Tirole (1991) (see their Theorem 4.1).

Then $(2,2) \in \mathcal{E}_T$ *(through **gradualism**) if and only if*

$$(3) \qquad \begin{cases} v - 2c \geq p(1,2)v - c, \\ p(0,1)v - c \geq p(0,2)v - 2c, \quad \text{and} \\ v - 2c \ \geq p(0,1)v. \end{cases}$$

[c] *Finally, if* $\mathcal{E}_N = \{(0,0)\}$ *and* (3) *hold, then* $(0,0) \in \mathcal{E}_T$.

Gradual cooperation requires that each player finds it optimal to make the remaining contribution in the second round if both have already made partial contributions in the first round (the first condition in (3)). It also entails that no player has an incentive to deviate from this sequence of partial contributions (the second and third conditions in (3)).

The first condition in (3) and the uniqueness of $\mathbf{e}_N^* = (0,0)$ imply that $p(0,2)v > v - 2c$, which together with the third condition in (3) above yield $p(0,2)v > v - 2c > p(0,0)v$. In other words, full cooperation Pareto-dominates shirking, though the latter prevails when there is no way to observe the ongoing contributions. There is mutual interest in cooperating, but it is not in any player's individual interest to cooperate. In this setting, making efforts observable encourages full cooperation. However, since efforts are irreversible, sinking two units of effort in the first round is risky, as the other player can exert zero effort in both rounds, get $p(0,0)v > v - 2c$, and go unpunished. (The only way to punish him would be for the cooperating player to move back to shirking, which is not possible.) Therefore, while transparency induces cooperation, it can only do so using partial commitments, i.e., gradually. The result is similar to the gradualism result of Lockwood and Thomas (2002). Earlier an empirical literature (Ichino and Maggi, 2000; Mas and Moretti, 2009) had pointed out the role of reciprocity in organizations, attributing it to behavioral effects. Our result shows that reciprocity can be explained on grounds of pure rationality and selfishness.

Thus gradualism is one way for transparency to make a difference when, without it, only the worst (i.e., shirking) would have realized. This may lead to a distinct cost advantage for a principal who wants to design reward incentives to uniquely implement full cooperation, as we will see in Proposition 4. Proposition 2 also prompts the question whether a similar domination could be achieved but without realizing full cooperation. In supplementary materials we verify that indeed this is possible, sometimes by achieving overall equilibrium efforts of $(2,1)$ in the transparent environment while $(0,0)$ is the only equilibrium under non-transparency.[15]

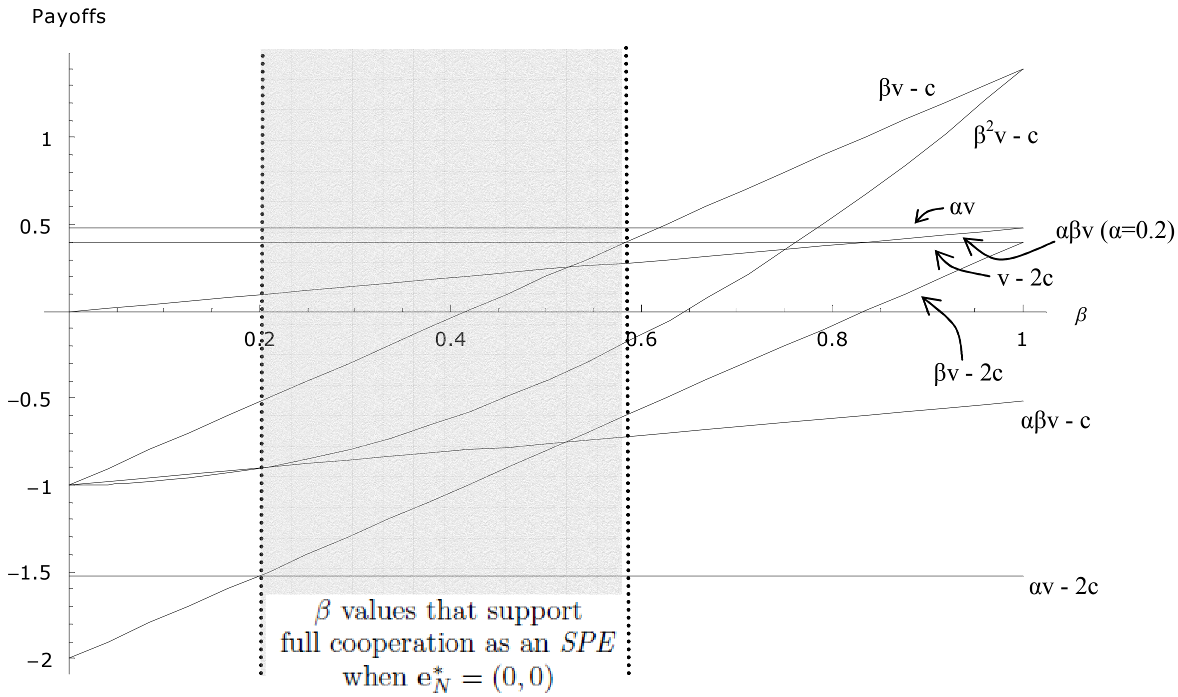

Figure 3: $(0,0)$ unique $\mathbf{e}_N^*$, and $(2,2)$ supported in *SPE*

Example. We now construct an example to illustrate Proposition 2, where full cooperation is induced only under transparency. Figure 3 is derived using perfectly complementary technology, $p(e_1, e_2) = p(e_1)p(e_2)$, where for $i = 1, 2$,

$$p(e_i) = \begin{cases} \alpha & \text{if } e_i = 0; \\ \beta & \text{if } e_i = 1; \\ 1 & \text{if } e_i = 2. \end{cases}$$

Given this specification, $p(0,2) = \alpha$, $p(1,2) = \beta$, $p(0,1) = \alpha\beta$, and $p(1,1) = \beta^2$. The figure plots the payoffs against β and identifies the values of β such that the payoffs satisfy conditions (3) for a profile of the remaining parameters, $(\alpha = \frac{1}{5}, v = 2.4, c = 1)$.[16] Further, $\mathbf{e}_N^* = (0,0)$ since for all $\beta \in (0,1)$, $\alpha^2 v > 0$, $\alpha\beta v - c < 0$, and $\alpha v - 2c < 0$ (i.e., $p(0,0)v > 0$,

[15]When $(2,1)$ obtains, it is more likely that $(0,0)$ will be eliminated which is a strict improvement, in contrast to the case of weak improvement when $(2,2)$ occurs along with $(0,0)$ (Proposition 2[c]).

[16]The figure has been generated in Mathematica.

$p(1,0)v - c < 0$, and $p(2,0)v - 2c < 0$). To verify uniqueness of $\mathbf{e}_N^* = (0,0)$, first note that $(1,1)$ is not an *NE* since $p(0,1)v > p(1,1)v - c$ (because $\alpha v > \beta^2 v - c$), and $(2,2)$ is not an *NE* because $p(0,2)v > v - 2c$ (follows from (3)), and there is no other pure strategy equilibrium (by Lemma 1).

Let us now denote the value of β at which $v - 2c = \beta v - c$ by β_1. In this example, $\beta_1 = \frac{7}{12}$, and we see that, for the given parameter values of (α, v, c), all the conditions (i.e., (3) as well as uniqueness of $\mathbf{e}_N^* = (0,0)$) are simultaneously satisfied for $\beta \in \left(\frac{1}{5}, \frac{7}{12}\right]$. ■

Next we develop the other main results on the performance of transparency vis-à-vis non-transparency for implementation of better effort profiles and the related optimal incentive costs. We begin with the claim that by allowing players to observe each other's efforts during the project's active phase, the principal would do no worse and possibly do better. For example, if full cooperation is an equilibrium in the one-shot game but not necessarily unique, then full cooperation must be the only equilibrium in the extensive-form game.

Define the set of outcomes ***inferior*** to $\mathbf{e}_N = (e_1, e_2)$ by

$$\mathcal{I}_{\mathbf{e}_N} = \left\{ (\tilde{e}_1, \tilde{e}_2) \mid \tilde{e}_1 < e_1 \text{ or } \tilde{e}_2 < e_2 \right\}.$$

Note that by this definition, $(2,0)$ and $(0,2)$ are inferior to the effort pair $(1,1)$.

We look at two cases: when partial cooperation is a one-shot equilibrium, and when full cooperation is a one-shot equilibrium.

LEMMA 2. *Suppose that $(1,1) \in \mathcal{E}_N$. Then under transparency overall efforts that entail shirking by any player cannot arise in an* SPE.

LEMMA 3. *Suppose that $(2,2) \in \mathcal{E}_N$. Then under transparency overall efforts where any player exerts less than two units of effort cannot arise in an* SPE.

Thus, making efforts observable eliminates all outcomes inferior to the 'best' one-shot equilibrium possible where 'best' is interpreted in terms of total team efforts.[17] But still elimination does not establish superiority of transparency. We must show that the best one-shot equilibrium, or perhaps a better effort profile, can be supported as a pure strategy *SPE* of the extensive-form game under transparency. The following proposition achieves this objective.

[17]This will also yield the highest chance of the project's success given that the one-shot game induces only symmetric *NE*.

Proposition 3 (**Beneficial Transparency**). *Suppose a joint project involves two complementary tasks. Then transparency dominates over non-transparency in the following sense:*

*Equilibrium (or equilibria) in the non-transparent environment entailing partial or full cooperation by both players is weakly improved upon in a **unique equilibrium** in the transparent environment by retaining the **best** equilibrium and at the same time by eliminating all **inferior** effort profiles (i.e., ones in which at least one player exerts lower effort).*

Moreover, under appropriate conditions, when shirking (i.e., $(0,0)$*) is a unique equilibrium under non-transparency, with transparency it is possible to achieve full cooperation by both players but not partial cooperation.*

Thus, when there are multiple one-shot equilibria, the weak dominance of transparency is achieved through (i) preservation of the best one-shot equilibrium and (ii) the elimination of all potential inferior outcomes (including inferior one-shot equilibria). When the one-shot equilibrium is unique and involves cooperation (partial or full), overall equilibrium efforts under transparency coincide with the efforts under non-transparency. Finally, when shirking is the unique one-shot equilibrium, transparency improves upon non-transparency by making full cooperation possible (under certain conditions) through partial commitments.

As already mentioned in the Introduction, relative to non-transparency the expanded strategies under transparency has the potential to result in additional equilibria and equally it could eliminate some one-shot equilibrium. Proposition 3 confirms both these predictions to be true but what is interesting is the uniform impact of the two effects to make transparency superior in terms of effort incentives (not only inferior outcomes are eliminated, strictly superior outcome may emerge). For an intuition note that with *complementary* efforts whenever there are multiple equilibria in the one-shot game, the equilibria can be strictly Pareto-ranked from the players' point of view with the equilibrium involving highest symmetric efforts dominating the lower symmetric efforts equilibrium (or equilibria). This allows a player to be unilaterally aggressive to play his 'best' one-shot equilibrium effort in the first round under observability. The unique best response of the other player, then, is to choose aggregate efforts over two rounds to correspond to his best one-shot *NE*. Thus, any player, through an aggressive play, can eliminate all inferior effort pairs (not just inferior *NE*) from being supported in *SPE*. By a similar logic, due to complementarity observability (of efforts) can generate strictly higher efforts than is possible under non-observability. Later on we will see that if, instead, the efforts are substitutes, transparency is either neutral or sometimes may even be harmful.

Another aspect worth emphasizing is that, while equilibrium selection using the criterion of Pareto domination may seem a valid reason not to worry about the inferior equilibria (in the case of multiple equilibria under non-transparency), the problem of miscoordination in team settings is a very reasonable concern which gets worse as the team size becomes large. And with the introduction of slight risk aversion on the part of the players (in our treatment players are risk neutral in monetary rewards), non-transparency is likely to tilt the balance towards lower efforts equilibria. Transparency fully resolves this coordination problem by eliminating the inferior equilibria.[18]

3.3 *The case of increasing marginal costs.*

So far our analysis has been based on the assumption of linear effort costs. We now briefly discuss possible modification to the main result if effort costs are convex: the cost of exerting the second unit of effort within the same round is $c+\delta$, $\delta > 0$, i.e., the marginal cost of effort is increasing within a round.

With the change in effort costs, our previous intuition in favor of transparency gets somewhat weakened. After all, due to increasing marginal costs players are strongly discouraged against sinking in two units of effort within a single round. This gives fewer options to contribute two units of effort in both the transparent and the non-transparent environments, as the players should like to space out their effort contributions over the two rounds. In the non-transparent environment this lack of options is of no real consequence, because the players can shift their contributions across the two rounds privately. But in the transparent environment, this creates a perverse incentive among the players to withhold individual contributions in the first round, thereby credibly conveying to the other player that pushing up contribution in a later round would be unlikely (this effect is the principal reason why transparency is potentially harmful in the substitution technology case). So players may well end up in a bad coordination under transparency with reduced first-round efforts and

[18]For example, in the case where $\mathbf{e}_N^* = (0,0)$, $\mathbf{e}_N^* = (1,1)$, and $\mathbf{e}_N^* \neq (2,2)$, transparency allows any player to confidently sink in one unit of effort early on regardless of whether the other player chooses zero effort or one, because when the other player observes his move it will be in his best interest to match it (if he has not already done so). Since this decision by any player will always be matched by the other player, a situation where one player partially cooperates and the other player shirks cannot arise with observability.

lower aggregate efforts. We show that, in our three efforts setup, such harmful effect never arises and transparency continues to be (weakly) better than non-transparency. The main difference, compared to the linear effort costs case, is that we can no longer guarantee the uniqueness of the overall equilibrium efforts in the extensive-form game. The formal analysis is developed in the supplementary materials section.

3.4 *Optimal rewards.*

So far we did not consider the question of optimal incentives: what should be the minimal rewards to induce a particular pair of aggregate efforts, with and without transparency? Does transparency lower the cost of incentives to the principal? One can well infer the answer from Proposition 3. Suppose that, given $p(\cdot,\cdot)$ and c, the principal wishes to set rewards such that full cooperation is the unique equilibrium with non-transparency. To minimize cost, he chooses the minimum of the set of feasible v values for which this is possible. But Proposition 3 implies that this minimum reward, as well as all feasible values for v that implement full cooperation *as only one* of multiple equilibria under non-transparency, induces full cooperation as the unique equilibrium under transparency. In other words, transparency expands the feasible range of v values for the principal: this may bring down the principal's optimal cost, and can never increase it.[19]

We verify the above claim using formal derivations (available online) that provide, given a complete breakdown of the cost parameter c in an ascending order (for any given value of v and the project technology $p(e_1, e_2)$), the list of various equilibria under the two arrangements, non-transparency and transparency. Based on this formal verification, we can make the following general observation:

PROPOSITION 4 (**Implementation costs**). *Consider the same joint project characterized by general complementarity, as in Proposition 3. Then full cooperation by both players, i.e., overall efforts* $(2, 2)$*, can be* ***uniquely*** (*or weakly*) *implemented under transparency for a reward that is no more and possibly less than the minimal reward needed for unique* (*respectively, weak*) *implementation under non-transparency.*

A result similar to Proposition 4 can be stated also for implementation of partial cooperation. Whether the principal targets full cooperation or partial cooperation should depend,

[19]The same assertion can be made also for 'weak' implementation.

of course, on the available budget.

3.5 *Non-identical players.*

While our analysis in this paper is carried out for identical players, we will argue that the main economic intuitions should apply more generally. Consider non-identical players – they may differ either in terms of the impact of their efforts on the project's success probability (i.e., $p(\cdot,\cdot)$ is not necessarily symmetric so that **A2** does not hold) or in effort costs (c_1 may differ from c_2, as opposed to $c_1 = c_2 = c$) or both. We will, however, retain the other assumptions, **A1**, **A3** and **A4**.[20] Also, we consider only the case of identical rewards, $v_1 = v_2 = v$; qualitatively, the treatment of differential rewards follows similar reasoning.

Our claim is that the main reason why transparency dominates non-transparency is because the Nash equilibria in the one-shot game can be Pareto ranked, due to complementarity of players' efforts. Roughly, compared to one *NE* if another *NE* involves higher efforts by at least one player and which leads to a higher chance of project success (and so preferred by the authority) while also improving the players' net payoffs, the players should like to play the second equilibrium and move away from the first under transparency: the player who strictly gains can take the initiative by putting in the corresponding amount of (possibly higher) efforts in the first round that is observed by the other player who, in turn, would reciprocate as there is nothing to lose if not gain.

The above intuition tells us why with multiple Nash equilibria in the one-shot game, the inferior equilibria should not arise under transparency. On the other hand, the intuition for gradualism in Proposition 2 does not depend on player symmetry. So combined with the Pareto ranking property, the weak dominance of transparency under complementary technology should continue to hold in the heterogeneous players case. Below we formally present the Pareto-ranking result:

Proposition 5 (**Pareto ranking of Nash equilibria: non-identical players**). *Consider a joint project characterized by general complementarity except that now the players are heterogeneous either in terms of the impact of their efforts on success probability or in effort costs* (*or both*)*. Then, whenever, under non-transparency, there are multiple Nash equilibria yielding different overall chances of success, the equilibria can be* (*weakly*) *Pareto ranked,*

[20] The analysis in the next section should also generalize, although we do not verify this.

with the players preferring the equilibrium with a higher success probability.

4 Substitution Technology: A Neutrality Result

In this section, we consider team projects with player efforts primarily as substitutes. The main objective is to see how the change from complementary to substitution technology impacts on the effect of transparency on team members' efforts.

To formalize, let the project's success probability inherit properties **A1-A3** from the previous section and satisfy the following property:

A4′. *General Substitutability*: For any $e_j \in \{0,1\}$, $p(1,e_j') - p(0,e_j') < p(1,e_j) - p(0,e_j)$ and $p(2,e_j') - p(1,e_j') < p(2,e_j) - p(1,e_j)$, where $e_j' > e_j$.

That is, the incremental probability of project success due to an extra unit of effort by a player is decreasing in the other player's effort.[21] We continue to assume linear effort costs. At the end we discuss the likely changes in results if one assumes increasing marginal costs.

4.1 *Unobservable contributions.*

Denote the one-shot simultaneous move game representing the effort contributions over two rounds without observability by Γ_N; note that it takes the same form as Figure 1. The *NE* of this game will be denoted by $\mathbf{e}_N^*$. There always exists a pure strategy *NE* in Γ_N (proof available online). In Appendix **A** we also establish the following result:

Lemma 4. *In the normal-form game Γ_N, multiple symmetric pure strategy Nash equilibria cannot arise. That is, any $\mathbf{e}_N^* = (e,e)$ must be a unique equilibrium.*

The intuition relies on a player's marginal benefit from effort being decreasing in the other player's effort. This means, if $(1,1)$ is an *NE* so that putting in one unit of effort is (weakly) better than putting in zero effort for a player, this comparison holds true strictly if the other player puts in zero effort. Hence $(0,0)$ cannot be an *NE*. The same intuition applies negating $(1,1)$ and $(2,2)$ being both *NE*.

[21] It is easy to check that in the perfect substitution case, $p(e_1,e_2) = p(e_1+e_2)$, the general substitutability property implies $p(1)-p(0) > p(2)-p(1) > p(3)-p(2) > p(4)-p(3) > 0$, i.e., $p(e_1,e_2)$ is strictly concave separately in each player's effort.

Note that while for complementary technology one-shot equilibrium is necessarily symmetric, for substitution technology one-shot equilibrium can be asymmetric. Moreover, an asymmetric equilibrium can arise along with a symmetric one-shot equilibrium.[22]

4.2 *Observable contributions.*

When first-round efforts are observable, the extensive form is as in Figure 2. Denote the extensive-form game under substitution technology by Γ_T, any (pure strategy) *SPE* of this game by $\mathbf{e}_T^*$, and the continuation game following $\mathbf{e_1} = (e_{11}, e_{21})$ by $\Gamma_T|_{(e_{11},e_{21})}$.

With player efforts as substitutes (rather than complements), free-riding becomes a more serious problem under either contribution format, with and without transparency, because one player's slack can be more easily picked up by another player. But then a player cannot easily free ride by simply putting in low effort in the first round because this effort reduction can be made up for by the same player by putting in more effort in the second round, given linear costs of effort. So how substitutability in efforts affects the players' overall effort incentives under the two formats is not a priori clear.

Our next result shows that unlike in the complementary technology case, when efforts are substitutes, transparency cannot eliminate inferior efforts equilibrium if there are multiple equilibria under non-transparency.

PROPOSITION 6. *Suppose a joint project satisfies general effort substitutability. Any* NE *efforts pair* (e_1^*, e_2^*) *under non-transparency can be supported as an* SPE *of the effort contribution game under transparency, with the strategy profile* $\mathbf{e}_T = (e_1^*, e_2^*; 0, 0)$.

The next result shows that any overall effort profile achievable under transparency can also be replicated in the one-shot game under non-transparency:

PROPOSITION 7. *Suppose a joint project satisfies general effort substitutability. If under transparency* $\mathbf{e}_T = (e_{11}^*, e_{21}^*; e_{12}^*(e_{11}^*, e_{21}^*), e_{22}^*(e_{11}^*, e_{21}^*))$ *is an* SPE, *then the aggregate efforts pair* $\mathbf{e}_N = (e_1^*, e_2^*)$, *where* $e_1^* = e_{11}^* + e_{12}^*$ *and* $e_2^* = e_{21}^* + e_{22}^*$, *is an* NE *of the effort contribution game under non-transparency.*

[22] For example, suppose that $v - 2c > p(1,2)v - c$ and $v - 2c = p(0,2)v$, such that $\mathbf{e}_N^* = (2,2)$. By Lemma 4, we know that $\mathbf{e}_N^* \neq (1,1)$ and $\mathbf{e}_N^* \neq (0,0)$. However, $v - 2c > p(1,2)v - c$ and $v - 2c = p(0,2)v$ imply that, using $\mathbf{A4'}$ and $\mathbf{A2}$, $p(0,2)v - 2c > p(2,1)v - c$ and $p(0,2)v - 2c > p(0,0)v$. Together with the fact that $v - 2c = p(0,2)v$, these conditions imply that $\mathbf{e}_N^* = (0,2)$.

Thus, Propositions 6 and 7 together establish, in contrast to our findings in section 3, a form of 'neutrality of transparency' when player efforts are substitutes and effort costs are linear: effort observability is neither gainful nor harmful for inducing efforts. The result further implies that if one were to explicitly design incentives to implement full cooperation (or partial cooperation), *the optimal reward, v, will be identical with and without transparency.*

To understand the intuitions behind the neutrality result, one must ask in what ways can observability of efforts make a difference. On the positive side, first observability could allow players, through gradualism, to coordinate on full cooperation (Proposition 2), but this advantage disappears with effort substitutability because more effort by one player decreases the incremental benefit from extra effort by the other player. (That is, complementarity in efforts is *necessary* for the special advantage of gradualism.) Second, while observability enables a player to put in high early efforts unilaterally and eliminate any Pareto-inferior equilibrium in the complementary technology case, with substitution high early efforts by one player does not improve incremental benefits from others' efforts, so there is no added incentive to reciprocate. This denies transparency any edge over non-transparency in terms of effort inducement. On the negative side, effort observability would normally allow a player, moving early, to commit to a low contribution so that others moving late must shore up their contributions, a threat especially meaningful under effort substitutability. But this threat loses its bite when the same player who contributed low early can make it up later on – again transparency makes no difference.

Related to the last point above, in a sequential voluntary contribution public good game Varian (1994) showed that total contribution under observability of contributions is often less than (and never exceeds) the total contribution under non-observability. In our setup, the fact that in the last round both players get to move a second time, combined with the fact that marginal cost of effort is constant, completely nullify the extra free-riding opportunity associated with an early move and observability makes no difference. But if marginal cost of effort is increasing, low contribution in the early round will have a commitment value similar to Varian's setup because to make it up in the second round will push up the player's effort costs at an increasing rate, making observability of efforts *harmful* (from the organization's point of view).[23] This result is demonstrated in Pepito (2010) in a continuous efforts formu-

[23] A similar contrast can be found between the dynamic contribution game of Admati and Perry (1991), which assumes sequential contributions, and the repeated contribution game of Marx and Matthews (2000),

lation of a two-player, two-round repeated efforts joint project game, assuming the players' efforts are substitutes.

Also as we discussed in the Introduction, our neutrality property of transparency is similar to Winter (2010)'s result. The important difference between Winter's setup and ours is that a player in our model may choose non-zero efforts over multiple rounds giving rise to *repeated* efforts contribution game, whereas in Winter's analysis a player gets to exert effort (or shirk) only once so that the effort investment game is mostly *sequential* in nature (late movers observe the early movers' efforts and not the other way around).[24]

5 Conclusion

Transparency is an important subject of debate in public economics and its applications in team settings. Samuelsonian formulation of public goods, in a majority of models, takes substitutability of contributions in public good's production as a starting point, with the free-rider problem as the main challenge. Team productions in organizations, on the other hand, may exhibit a large degree of complementarity, while the benefits of team performance are similar to a public good.

To see how the paper adds to the literature on transparency, in Table 1 we present a summary of the main features and results of our model and three related papers. Our model has the following attributes: joint (or team) project, repeated contribution of efforts, self-interested utilitarian contributors (whose preferences we describe as "standard preferences"), complete information, and the two types of production technologies – complementary and substitutes.

Of the papers listed in Table 1, Varian (1994) is in pure public good setting. Winter's (2010) is in a team setting (similar to ours) analyzing the architecture of information (i.e., how different peers are positioned in the observability-of-efforts chain) and its implications for what should be the right kind of team (function-based or process-based) from the optimal design viewpoint. Except Mohnen et al. (2008), all the papers listed assume standard utilitarian agents; Mohnen et al. consider the implications when agents view an inequitable

which assumes simultaneous contributions within each round.

[24] In Winter's setup, in some of the stages more than one worker may move (simultaneously) in which case they do not observe each other's efforts, but the late movers do observe the early movers' efforts.

Table 1: **Alternative related models of transparency**

This paper	Mohnen et al.	Winter[2010]	Varian
complete info.	complete	complete/ incomplete	complete
effort contr.	effort contr.	effort contr.	public good
repeat contr.	repeat contr.	mainly sequential; simult. in some stages	sequential
standard preferences	inequity aversion#	standard preferences	standard preferences
complementary tech.; transparency adv.	substitution; transparency adv.	complementary; transparency adv.	substitution; transparency disadv.
substitution tech.; transparency neutral[a]	#change to std. pref. ⇒ transparency neutral	substitution; transparency neutral	–

[a] True for linear costs; for convex costs, transparency harmful (Pepito, 2010)

distribution of the burden of contribution with extra aversion beyond the direct utility-of-rewards calculations.

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A Appendix

Proof of Lemma 1. Suppose without loss of generality $\mathbf{e}_N^* = (e_1^*, e_2^*)$, where $e_1^* > e_2^*$. Let $e_1^* - e_2^* = \triangle e \in \{1, 2\}$. Then it must be that

$$p(e_1^*, e_2^*) - ce_1^* \geq p(e_1^* - \triangle e, e_2^*) - c[e_1^* - \triangle e] \tag{A.1}$$

$$\text{and} \quad p(e_2^*, e_1^*) - ce_2^* \geq p(e_2^* + \triangle e, e_1^*) - c[e_2^* + \triangle e]. \tag{A.2}$$

From (A.1) we see that $p(e_1^*, e_2^* + \triangle e) - ce_1^* > p(e_1^* - \triangle e, e_2^* + \triangle e) - c[e_1^* - \triangle e]$, by **A4**. But this implies that $p(e_2^* + \triangle e, e_1^*) - c[e_2^* + \triangle e] > p(e_2^*, e_1^*) - ce_2^*$, contradicting (A.2). ■

Proof of Proposition 1. Equilibrium $(e_1^*, e_2^*) = (0, 0)$ occurs if and only if $p(0, 0)v \geq p(1, 0)v - c$ and $p(0, 0)v \geq p(2, 0)v - 2c$, i.e., $c \geq \max\{(p(1, 0) - p(0, 0))v, [(p(2, 0) - p(0, 0))v]/2\}$, which is satisfied for high c values. Equilibrium $(e_1^*, e_2^*) = (1, 1)$ occurs if and only if $p(1, 1)v - c \geq p(0, 1)v$ and $p(1, 1)v - c \geq p(2, 1)v - 2c$, i.e., $(p(2, 1) - p(1, 1))v \leq c \leq (p(1, 1) - p(0, 1))v$. Finally, equilibrium $(e_1^*, e_2^*) = (2, 2)$ occurs if and only if $v - 2c \geq p(1, 2)v - c$ and $v - 2c \geq p(0, 2)v$, i.e., $c \leq \min\{(1 - p(1, 2))v, [(1 - p(0, 2))v]/2\}$, which is clearly satisfied for low values of c. ■

Proof of Proposition 2. $[a](i)$ First we claim that full cooperation cannot be achieved in the extensive-form game through $(0, 0; 2, 2)$ or $(2, 2; 0, 0)$. The first case implies that $(2, 2)$ is an *NE* in the continuation game following $\mathbf{e_1} = (0, 0)$, contradicting our hypothesis that $(2, 2) \neq \mathbf{e}_N^*$ (recall, the continuation game following $\mathbf{e_1} = (0, 0)$ is simply $\mathcal{G}_N$). The second case cannot be supported in equilibrium as any player i would have an incentive to deviate from $e_{i1} = 2$ to either $e_{i1} = 1$ or $e_{i1} = 0$, because full cooperation is not an equilibrium in the one-shot game: in the extensive form i can deviate the same way as he would have done in the one-shot game, first by deviating in the first round (as in the one-shot game) and then putting in zero effort in the second round.

Next consider full cooperation of the form $(2, 1; 0, 1)$ or $(1, 2; 1, 0)$ and each player collecting a payoff of $v - 2c$ overall. Since $(2, 2) \neq \mathbf{e}_N^*$, at least one of the following must hold (see Figure 1):

$$p(0, 2)v > v - 2c, \tag{A.3}$$

$$p(1, 2)v - c > v - 2c. \tag{A.4}$$

But then the player who is considering to cooperate gradually in the extensive-form game (say, player 1) can *either* shirk in both rounds and obtain an overall payoff $p(0, 2)v$ that exceeds $v - 2c$, *or* partially cooperate in the first round and shirk in the second round to receive $p(1,2)v - c$ that exceeds $v - 2c$; one of these profitable deviations must be possible, by (A.3) and (A.4). Thus, neither $(2,1;0,1)$ nor $(1,2;1,0)$ can be sustained as *SPE*.

Then consider $(0,1;2,1)$ (or similarly $(1,0;1,2)$) as an equilibrium possibility. It is easy to see that there is a profitable deviation for player 1 in the second round, given that one of (A.3) and (A.4) must be true.

The above eliminations leave us with gradual cooperation, i.e. $(1,1;1,1)$, as the only equilibrium possibility.

(*ii*) In the extensive form, $(e^*_{12}(1,1), e^*_{22}(1,1)) = (1,1)$ if and only if $(1 - p(1,1))v - c \geq (p(1,2) - p(1,1))v$ (see Figure 2), i.e.,

$$v - 2c \geq p(1,2)v - c.$$

Further, since $(2,2) \neq \mathbf{e}^*_N$, (A.3) must apply given that $v - 2c \geq p(1,2)v - c$. Condition (A.3) and $v - 2c \geq p(1,2)v - c$ (an implication of gradualism) imply that

$$(p(1,2) - p(0,2))v < c,$$

or that $(p(1,1) - p(0,1)) < c$, by **A4**. Therefore, $\mathbf{e}^*_N \neq (1,1)$, by Proposition 1.
[*b*] Refer to Figure 1. Clearly, $\mathbf{e}^*_N = (0,0)$ is unique if and only if

$$\text{(A.5)} \qquad p(0,0)v \geq \max\{p(1,0)v - c, p(2,0)v - 2c\},$$

$$\text{(A.6)} \qquad p(1,1)v - c < \max\{p(0,1)v, p(2,1)v - 2c\},$$

$$\text{(A.7)} \qquad \text{and} \qquad v - 2c < \max\{p(0,2)v, p(1,2)v - c\}.$$

Note that for (A.6) and (A.7) to hold simultaneously, it must be that

$$\max\{p(0,1)v, p(2,1)v - 2c\} = p(0,1)v.$$

Suppose not, so that $\max\{p(0,1)v, p(2,1)v-2c\} = p(2,1)v-2c$. Then this condition together with (A.6) would imply that $p(1,1)v - c < p(2,1)v - 2c$ and $p(0,1)v < p(2,1)v - 2c$, or that (using **A4**) $c < [1 - p(1,2)]v$ and $c < \frac{[1-p(0,2)]v}{2}$, respectively. But by Proposition 1 these conditions imply that $\mathbf{e}^*_N = (2,2)$, a contradiction. Therefore, $\mathbf{e}^*_N = (0,0)$ is unique if and only if conditions (A.5), (A.7), and

$$\text{(A.8)} \qquad p(1,1)v - c < \max\{p(0,1)v, p(2,1)v - 2c\} = p(0,1)v$$

hold.

[**Sufficiency proof.**] We claim that if (3) holds, then $\mathbf{e}_T^* = (1, 1; 1, 1)$, i.e.,

- $(e_{i2}^*(1, 1), e_{j2}^*(1, 1)) = (1, 1)$; and
- there is no profitable unilateral deviation for any player in Round 1 from $\mathbf{e_1} = (1, 1)$.

We are going to show that the following strategies will form an *SPE*:

1. In the first round, $e_{i1}^* = 1$ for each player i, and
2. In the second round, for $i = 1, 2$,

(A.9)
$$e_{i2}^* = \begin{cases} 0 & \text{if} \quad \mathbf{e_1} = (\tilde{e}_{i1}, \tilde{e}_{j1}) \ \text{ and } \ \tilde{e}_{i1} \neq 1 \ ; \\ 0 & \text{if} \quad \mathbf{e_1} = (1, 0) \ ; \\ 1 & \text{if} \quad \mathbf{e_1} = (1, \tilde{e}_{j1}) \ \text{ and } \ \tilde{e}_{j1} > 0. \end{cases}$$

By the first condition in (3), $(1 - p(1, 1))v - c \geq (p(1, 2) - p(1, 1))v$, hence $(e_{i2}^*(1, 1), e_{j2}^*(1, 1)) = (1, 1)$. Now we show that there is no profitable unilateral deviation in Round 1.

The strategy profile in the posited equilibrium, $(1, 1; 1, 1)$, yields a payoff to player 1 of $u_1(1, 1; 1, 1) = v - 2c$. Suppose he lowers his first-round contribution to $e_{11} = 0$. Then in the continuation game, (A.9) recommends $(e_{12}, e_{22}) = (0, 0)$. To verify that it is an *NE*, first note that choosing $e_{22} = 0$ is player 2's best response to $e_{12} = 0$ by the second condition in (3). Also, note that if (A.7) and the first condition in (3) simultaneously apply, it must be that

(A.10)
$$p(0, 2)v > v - 2c \quad \text{and} \quad p(0, 2)v > p(1, 2)v - c,$$

which in turn implies, by **A4**, that

(A.11)
$$p(0, 1)v > p(2, 1)v - 2c \quad \text{and} \quad p(0, 1)v > p(1, 1)v - c.$$

By (A.11), player 1 choosing $e_{12} = 0$ is a best response to $e_{22} = 0$, verifying *NE*. Now, by the third condition in (3), $u_1(0, 1; 0, 0) = p(0, 1)v \leq v - 2c = u_1(1, 1; 1, 1)$, so player 1 will not find the deviation in the first round profitable (and, by symmetry, the same is true of player 2). Finally, suppose player 1 increases his contribution to $e_{11} = 2$. Then the first condition in (3) implies that $e_{22} = 1$, as recommended in (A.9), is a best response by player 2. Player 1's deviation thus results in the payoff $u_1(2, 1; 0, 1) = v - 2c = u_1(1, 1; 1, 1)$, which is clearly not profitable. Similarly, player 2 will not deviate in Round 1.

Finally we show that (A.9) corresponds to *NE* following joint deviations, i.e., in the subgames following $\mathbf{e_1} = (0,0)$, $\mathbf{e_1} = (2,0)$, $\mathbf{e_1} = (0,2)$, and $\mathbf{e_1} = (2,2)$. Suppose players lower first-round contributions to $e_{i1} = 0$, $i = 1,2$. Note that the resulting continuation game is identical to the one-shot game $\mathcal{G}_N$ and that $\mathbf{e}_N^* = (0,0)$; therefore $e_{12} = 0$ and $e_{22} = 0$, as recommended by (A.9), form an *NE*. Next, suppose that player 1 raises his first-round contribution to $e_{11} = 2$ while player 2 lowers his contribution to $e_{21} = 0$. Then by condition (A.10) (that must hold if (A.7) and the first condition in (3) simultaneously apply, as established above), player 2's best response is $e_{22} = 0$; this is consistent with (A.9). (By symmetry, the same argument holds for player 1 following $\mathbf{e_1} = (0,2)$.) Finally, if both raise their first-round contributions to 2, no further contributions are possible, exactly as (A.9) specifies.

[**Necessity proof.**] Note that for $(e_{i2}^*(1,1), e_{j2}^*(1,1)) = (1,1)$ to arise, it must be that $(1 - p(1,1))v - c \geq (p(1,2) - p(1,1))v$, i.e., $v - 2c \geq p(1,2)v - c$. This is the first condition in (3).

Next, note that in the subgame following $(0,1)$, conditions (A.10) and (A.11) (that follow from (A.7), the first condition in (3) and **A4**, as established above) imply that $e_{21} = 0$ is player 1's strictly dominant strategy. This then leaves only two possible *NE* in this subgame: $(0,0)$ and $(0,1)$. If player 2 chooses $e_{22} = 1$, then player 1's payoff is $u_1(0,1;0,1) = p(0,2)v \underbrace{>}_{\text{by (A.10)}} v - 2c = u_1(1,1;1,1)$, making the deviation profitable. Therefore, the deviation is unprofitable only if $(0,0)$ is played following $\mathbf{e_1} = (0,1)$ (i.e., only if player 2 chooses $e_{22} = 0$ given that $e_{12} = 0$, or that $p(0,1)v - c \geq p(0,2)v - 2c$) *and* $u_1(0,1;0,0) = p(0,1)v - c \leq v - 2c = u_1(1,1;1,1)$. Thus, the second and third conditions in (3) follow.

[*c*] Shirking in the one-shot game implies that $(e_{12}^*(0,0), e_{22}^*(0,0)) = (0,0)$. So for $(0,0;0,0)$ to be an *SPE*, we must rule out deviations in the first round. In the proposed *SPE*, any player i, say player 2, will receive $u_2(0,0;0,0) = p(0,0)v$. Consider the possibility of player 2 deviating to $e_{21} = 1$. As argued earlier (under Sufficiency), $(e_{12}, e_{22}) = (0,0)$ is an *NE* following $(0,1)$; this yields to player 2 the payoff $u_2(0,1;0,0) = p(0,1)v - c \underbrace{\leq}_{(\mathbf{e}_N^* = (0,0))} p(0,0)v = u_2(0,0;0,0)$, so the deviation is not gainful. Suppose now that player 2 deviates by choosing $e_{21} = 2$; by condition (A.10) (which follows from (A.7) and the first condition in (3)), player 1 will choose $e_{12} = 0$. The deviation results in the payoff $u_2(0,2;0,0) = p(0,2)v - 2c \underbrace{\leq}_{(\mathbf{e}_N^* = (0,0))} p(0,0)v =$

$u_2(0,0;0,0)$, hence is not gainful. Therefore, $\mathbf{e}_T^* = (0,0;0,0)$. ■

PROOF OF LEMMA 2. Let $\mathbf{e}_N^* = (1,1)$, and by definition $\mathcal{I}_{(1,1)} = \{(0,0),(1,0),(0,1),(2,0),(0,2)\}$. By Proposition 1,

$$(p(1,1) - p(0,1))v - c \;\geq\; 0 \tag{A.12}$$

$$\text{and} \qquad (p(2,1) - p(1,1))v \;\leq\; c. \tag{A.13}$$

Fix any $(\tilde{e}_1, \tilde{e}_2) \in \mathcal{I}_{(1,1)} \setminus (0,0)$. By Lemma 1, such $(\tilde{e}_1, \tilde{e}_2)$ cannot be an *SPE* with the strategy profile $(0,0;\tilde{e}_1,\tilde{e}_2)$. This is so because the continuation game following $\mathbf{e_1} = (0,0)$ is strategically equivalent to the one-shot game $\mathcal{G}_N$.

Consider elimination of overall efforts $(1,0)$. Since $(0,0;1,0)$ cannot be an *SPE*, what remains to be shown is that $(1,0;0,0)$ is *not* subgame-perfect. Player 1's payoff $u_1(1,0;0,0) = p(1,0)v - c$; but then player 1 can deviate in Round 1 to $e_{11} = 0$ while player 2 chooses $e_{21} = 0$, and with $(1,1)$ being an *NE* in the continuation game (because $\mathbf{e}_N^* = (1,1)$) player 1 will receive an overall payoff of $u_1(0,0;1,1) = p(1,1)v - c$. Thus, player 1 would benefit ($p(1,1)v - c > p(1,0)v - c$, by **A3**), ruling out $(1,0;0,0)$ as an *SPE*. So, under transparency, overall efforts of $(1,0)$, and by symmetry $(0,1)$, cannot be supported in equilibrium.

Next consider overall efforts $(2,0)$. We know that $(0,0;2,0)$ cannot be an *SPE*. Consider then the strategies $(2,0;0,0)$. By (A.12) and invoking **A2** and **A4**, $(p(2,1) - p(2,0))v - c > 0$, so following $(2,0)$ player 2 will gain by choosing $e_{22} = 1$ over $e_{22} = 0$ (see Figure 2). Therefore, $(e_{12}^*(2,0), e_{22}^*(2,0)) \neq (0,0)$, hence $(2,0;0,0)$ is not an *SPE*. Finally, consider $(1,0;1,0)$. By (A.13) and invoking **A4**, $(p(2,0) - p(1,0))v - c < 0$: if following $(1,0)$ player 2 chooses $e_{22} = 0$, player 1 would choose $e_{12} = 0$ instead of $e_{12} = 1$, so $(1,0)$ cannot be an *NE* following $(1,0)$; this rules out $(1,0;1,0)$ as an *SPE*. Thus, overall efforts $(2,0)$, and by symmetry $(0,2)$, cannot be supported in equilibrium.

Finally, consider overall efforts $(0,0)$. There are two subcases to be considered.

If $\mathbf{e}_N^* \neq (0,0)$, then by the following result we claim that overall efforts of $(0,0)$ cannot arise in equilibrium of $\mathcal{G}_T$. This lemma will also be used to prove subsequent results.

LEMMA A.1. *If* $(0,0) \neq \mathbf{e}_N^*$, *then* $(0,0) \neq \mathbf{e}_T^*$.

PROOF. Online supplementary materials.

Alternatively suppose $\mathbf{e}_N^* = (0,0)$, in addition to $\mathbf{e}_N^* = (1,1)$. We claim that here too overall efforts of $(0,0)$ cannot be supported in equilibrium of $\mathcal{G}_T$. To see this, note that by

(A.12) and (A.13) and invoking **A2**, we can conclude that $(0,1)$ is an *NE* in the continuation game following $\mathbf{e_1} = (1,0)$ (see Figure 2). Moreover, using (A.12) directly and invoking **A3**, we see that $u_1(1,0;0,1) = p(1,1)v - c \geq p(0,1)v > p(0,0)v = u_1(0,0;0,0)$. This shows that first-round efforts $(0,0)$ cannot be supported as part of an equilibrium in the extensive-form game, since player 1 (in fact, any player) would have an incentive to undertake a first-round unilateral deviation by choosing $e_{11} = 1$ which will be followed up in Round 2 by $(0,1)$ as an *NE*. Therefore, once again overall efforts, $(0,0)$, cannot be supported in equilibrium of $\mathcal{G}_T$.

This completes the proof that overall efforts in $\mathcal{I}_{(1,1)}$ cannot be supported in *SPE*. ■

Proof of Lemma 3. Let $\mathbf{e}_N^* = (2,2)$, and by definition

$$\mathcal{I}_{(2,2)} = \{(0,0),(1,0),(0,1),(2,0),(0,2),(1,2),(2,1),(1,1)\}.$$

By Proposition 1,

$$(1 - p(1,2))v - c \geq 0 \tag{A.14}$$

$$\text{and} \quad (1 - p(0,2))v - 2c \geq 0. \tag{A.15}$$

Fix any $(\tilde{e}_1, \tilde{e}_2) \in \mathcal{I}_{(2,2)} \setminus \{(0,0),(1,1)\}$. By Lemma 1, such $(\tilde{e}_1, \tilde{e}_2)$ cannot be supported in an *SPE* with the strategy profile $(0,0;\tilde{e}_1,\tilde{e}_2)$; the continuation game following $\mathbf{e_1} = (0,0)$ is strategically equivalent to the one-shot game $\mathcal{G}_N$. Note that, by construction $\tilde{e}_1 \neq \tilde{e}_2$.

Consider elimination of overall efforts $(1,0)$. Since $(0,0;1,0)$ cannot be an *SPE*, what remains to be shown is that $(1,0;0,0)$ is *not* subgame-perfect. Player 1's payoff is $u_1(1,0;0,0) = p(1,0)v - c$; but then player 1 can deviate in Round 1 to $e_{11} = 0$ while player 2 chooses $e_{21} = 0$, and with $(2,2)$ being an *NE* in the continuation game (because $\mathbf{e}_N^* = (2,2)$) player 1 will receive an overall payoff of $u_1(0,0;2,2) = v - 2c$. This makes player 1 better off since

$$u_1(0,0;2,2) = v - 2c \underbrace{\geq}_{\text{by (A.14)}} p(1,2)v - c \underbrace{>}_{\text{by } \mathbf{A3}} p(1,0)v - c = u_1(1,0;0,0).$$

Therefore, overall efforts $(1,0)$, and by symmetry $(0,1)$, cannot be supported in *SPE*.

Consider overall efforts $(2,0)$. Aside from $(0,0;2,0)$, which we already argued cannot be an *SPE*, these efforts can also arise via the strategy profiles $(2,0;0,0)$ and $(1,0;1,0)$. First consider $(2,0;0,0)$ in which player 1 receives $p(2,0)v - 2c$. But then player 1 can deviate in Round 1 to $e_{11} = 0$, following which $(e_{12}, e_{22}) = (2,2)$ is an *NE* in the continuation game (since $\mathbf{e}_N^* = (2,2)$) and player 1 receives a higher payoff, $u_1(0,0;2,2) = v - 2c$. Hence $(2,0;0,0)$ is not an *SPE*.

Consider next the strategy profile $(1,0;1,0)$. Again, similar to the case just analyzed, player 1 can deviate in Round 1 to $e_{11} = 0$, following which $(e_{12}, e_{22}) = (2,2)$ realizes and player 1 is strictly better off compared to his payoff of $u_1(1,0;1,0) = p(2,0)v - 2c$. Hence $(1,0;1,0)$ cannot be an *SPE*.

Thus, overall efforts $(2,0)$, and by symmetry $(0,2)$, cannot be supported in *SPE*.

Consider overall efforts $(1,1)$. We claim that overall efforts $(1,1)$ cannot be supported in an *SPE*. Corresponding to overall efforts $(1,1)$, the strategy profile in the extensive form is one of the following: $(0,0;1,1)$, $(1,1;0,0)$, $(1,0;0,1)$, $(0,1;1,0)$. Each of these profiles yields player 1 a payoff of $p(1,1)v - c$, and since $v - 2c \geq p(1,2)v - c$ (recall, $\mathbf{e}_N^* = (2,2)$) it follows, using **A3**, that $v - 2c > p(1,1)v - c$. It is now easy to see that none of the strategy profiles will be *SPE*: given a first-round deviation by player 1 to $e_{11} = 2$, in Round 2 player 2 choosing an effort such that overall efforts are $(2,2)$ is an *NE*. This would result in a payoff of $v - 2c$ to player 1, which exceeds his payoff $p(1,1)v - c$ in the posited equilibrium. Thus, under transparency, overall efforts of $(1,1)$ cannot be supported in equilibrium.

Consider overall efforts $(2,1)$. The strategy profiles that yield these overall efforts are $(2,1;0,0)$, $(2,0;0,1)$, $(1,1;1,0)$, $(1,0;1,1)$, $(0,1;2,0)$, and $(0,0;2,1)$. Note that in each of these profiles player 1 receives a payoff of $p(2,1)v - 2c$. First, it has already been established at the beginning that the strategy profile $(0,0;2,1)$ cannot be an *SPE*. Next, examine the strategy profiles $(2,1;0,0)$ and $(2,0;0,1)$. Neither of these strategy profiles will be an *SPE*: given a first-round deviation by player 1 to $e_{11} = 1$ in either strategy profile, $(e_{12}, e_{22}) = (1, 2 - e_{21})$ is an *NE* in the continuation game that follows (since $\mathbf{e}_N^* = (2,2)$), which results in a payoff of $u_1(1,1;1,1) = u_1(1,0;1,2) = v - 2c \geq p(2,1)v - c > p(2,1)v - 2c$ (the first inequality follows from (A.14) and applying **A2**). Now consider the strategy profile $(1,1;1,0)$. For $(1,0)$ to be an *NE* following $\mathbf{e_1} = (1,1)$, and given that $\mathbf{e}_N^* = (2,2)$ (in particular, note condition (A.14) and property **A2**), the following conditions must hold (see Figure 2):

(A.16)	Player 1's best-response	:	$0 \leq (p(2,1) - p(1,1))v - c$
	Player 2's best-response	:	$(p(2,1) - p(1,1))v = (1 - p(1,1))v - c$
(A.17)			i.e., $0 = (1 - p(2,1))v - c.$

However, these conditions are inconsistent, given **A4** and **A2**. Therefore, $(e_{12}^*(1,1), e_{22}^*(1,1)) \neq (1,0)$, and $(1,1;1,0)$ is not an *SPE*. Moreover, note that conditions (A.16) and (A.17) must also hold for $(2,0)$ to be an *NE* following $\mathbf{e_1} = (0,1)$ and for $(1,1)$ to be an *NE* following $\mathbf{e_1} = (1,0)$. Since these conditions are inconsistent, then $(e^*_{12}(0,1), e^*_{22}(0,1)) \neq (2,0)$ and $(e^*_{12}(1,0), e^*_{22}(1,0)) \neq (1,1)$, and the strategy profiles $(0,1;2,0)$ and $(1,0;1,1)$ are not *SPE*. Therefore, none of the strategy profiles yielding overall efforts $(2,1)$, and by symmetry $(1,2)$, can be *SPE*.

What is left now is to show that overall efforts of $(0,0)$ cannot be supported in an *SPE*. There are three subcases to be considered.

First consider the subcase where $\mathbf{e}^*_N \neq (0,0)$. By Lemma A.1, overall efforts $(0,0)$ cannot arise in an *SPE*.

Next, suppose $\mathbf{e}^*_N = (2,2)$, $\mathbf{e}^*_N = (0,0)$, and $\mathbf{e}^*_N \neq (1,1)$. While $(0,0)$ is clearly an *NE* in the continuation game following $\mathbf{e_1} = (0,0)$, $(0,0;0,0)$ cannot be sustained as an equilibrium in the overall game since a first-round unilateral deviation to $e_{11} = 2$ by player 1 is gainful:

$$u_1(2,0;0,2) = v - 2c \underbrace{\geq}_{\text{by (A.15)}} p(0,2)v > p(0,0)v = u_1(0,0;0,0),$$

thus ruling out overall efforts of $(0,0)$ in an equilibrium of $\mathcal{G}_T$.

Finally, consider the subcase where all symmetric equilibria arise in the one-shot game. By Lemma 2, overall efforts of $(0,0)$ cannot be supported in an equilibrium of $\mathcal{G}_T$. ■

Proof of Proposition 3. We divide the proof into three parts.

[**1**] First suppose that $\mathbf{e}^*_N = (1,1)$ but $\mathbf{e}^*_N \neq (2,2)$; this equilibrium may be unique or there could be another equilibrium $\mathbf{e}^*_N = (0,0)$. Then, we show that the overall efforts $(1,1)$ can be supported as an *SPE* in the extensive-form game, and the equilibrium (in terms of overall efforts) will be unique.

By Proposition 1, $\mathbf{e}^*_N = (1,1)$ if and only if

$$(p(2,1) - p(1,1))v \leq c \leq (p(1,1) - p(0,1))v. \tag{A.18}$$

Consider the strategy profile $(1,0;0,1)$. By condition (A.18), we know that $(0,1)$ is an *NE* in the continuation game following first-round efforts $(1,0)$.

Coming back to Round 1, suppose player 1 unilaterally deviates to $e_{11} = 0$. Since $\mathbf{e}^*_N = (1,1)$, and the continuation game following $\mathbf{e_1} = (0,0)$ is simply $\mathcal{G}_N$, therefore $(e^*_{12}(0,0), e^*_{22}(0,0)) = (1,1)$. This yields the payoff $p(1,1)v - c$ to player 1, the same as his payoff before the deviation. Hence, deviation to $e_{11} = 0$ is not gainful for player 1.

Moreover, since $\mathbf{e}_N^* \neq (2,2)$, if player 1 deviates unilaterally in Round 1 by choosing $e_{11} = 2$, then player 2 will not choose $e_{22} = 2$. Specifically, player 2 will choose $e_{22} = 1$ in strict preference over $e_{22} = 0$: the right-hand side (weak) inequality in (A.18) implies that $(p(2,1) - p(2,0))v - c > 0$, by **A2** and **A4**. Consequently, this deviation is not gainful for player 1 since, by (A.18), $u_1(2,0;0,1) = p(2,1)v - 2c \leq p(1,1)v - c = u_1(1,0;0,1)$. Thus, there is no profitable deviation for player 1.

There is also no profitable deviation for player 2 in Round 1. To see this, suppose player 2 deviates in Round 1 to $e_{21} = 2$. Then by our argument in the previous paragraph but the players' roles reversed, in the continuation game player 1 will choose $e_{12} = 0$, and

$$u_2(1,2;0,0) = p(1,2)v - 2c \underbrace{\leq}_{(\mathbf{e}_N^*=(1,1))} p(1,1)v - c = u_2(1,0;0,1).$$

Next, suppose player 2 deviates to $e_{21} = 1$. Then $(e_{12}, e_{22}) = (0,0)$ is an *NE* in the continuation game following $\mathbf{e_1} = (1,1)$, since $(p(2,1) - p(1,1))v \leq c$ (by (A.18)). Thus, $u_2(1,1;0,0) = p(1,1)v - c = u_2(1,0;0,1)$.

Thus, overall efforts $(1,1)$ is supported as an *SPE* with $(1,0;0,1)$.

Next note that the overall efforts of $(2,2)$ cannot be supported in an *SPE* of $\mathcal{G}_T$, by Proposition 2[a]. Moreover, by Lemma 2, none of the overall efforts that are inferior to $(1,1)$ can be supported as *SPE*. Also, overall efforts $(2,1)$, and by symmetry $(1,2)$, cannot be supported as *SPE*. To show this, consider overall efforts $(2,1)$ which can result from any of the following strategy profiles: $(0,0;2,1)$, $(1,1;1,0)$, $(1,0;1,1)$, $(0,1;2,0)$, $(2,0;0,1)$, and $(2,1;0,0)$. By Lemma 1, $(e_{12}^*(0,0), e_{22}^*(0,0)) \neq (2,1)$, hence $(0,0;2,1)$ cannot be an *SPE*. Next, consider $(1,1;1,0)$. If $(1,0)$ is an *NE* in the continuation game following $\mathbf{e_1} = (1,1)$, then by **A4** and **A2** respectively,

$$\text{(A.19)} \qquad (p(2,1) - p(1,1))v - c \geq 0, \quad \text{i.e.,} \quad (1 - p(1,2))v - c > 0$$

$$\text{(A.20)} \qquad \text{and } \; 0 \geq (p(2,2) - p(2,1))v - c, \quad \text{i.e.,} \quad 0 \geq (1 - p(1,2))v - c.$$

However, these conditions are inconsistent. Therefore, $(e_{12}^*(1,1), e_{22}^*(1,1)) \neq (1,0)$, and $(1,1;1,0)$ cannot be an *SPE*. By the same argument, the profiles $(1,0;1,1)$ and $(0,1;2,0)$ cannot be *SPE*: both $(e_{12}^*(1,0), e_{22}^*(1,0)) = (1,1)$ and $(e_{12}^*(0,1), e_{22}^*(0,1)) = (2,0)$ require that conditions (A.19) and (A.20) simultaneously hold, an impossibility. Next, the strategy profile $(2,0;0,1)$ is an *SPE* only if $(e_{12}^*(2,0), e_{22}^*(2,0)) = (0,1)$, which in turn requires

$$(p(2,1) - p(2,0))v - c \geq (1 - p(2,0))v - 2c, \quad \text{i.e.,} \quad 0 \geq (1 - p(2,1))v - c.$$

Consequently, by **A2** and then **A4**, $0 > (p(2,1) - p(1,1))v - c$, i.e., $p(1,1)v - c > p(2,1)v - 2c$, thus player 1 gains from a unilateral first-round deviation to $e_{11} = 1$: following $\mathbf{e_1} = (1,0)$, in the continuation game $(0,1)$ is an *NE* (since $\mathbf{e}_N^* = (1,1)$), and $u_1(1,0;0,1) = p(1,1)v - c > p(2,1)v - 2c = u_1(2,0;1,0)$. Therefore, $(2,0;1,0)$ cannot be an *SPE*. Finally, consider the strategy profile $(2,1;0,0)$. For $(e_{12}^*(2,1), e_{22}^*(2,1)) = (0,0)$ to arise, it must be that $0 \geq (1 - p(2,1))v - c$, which implies that, by **A2** and **A4**, $0 > (p(2,1) - p(1,1))v - c$, or that $p(1,1)v - c > p(2,1)v - 2c$. But then player 1 will find unilateral deviation to $e_{11} = 1$ gainful, because $(e_{12}^*(1,1), e_{22}^*(1,1)) = (0,0)$ (established earlier to rule out first-round deviation to $e_{21} = 1$ from $(1,0;0,1)$) and $u_1(1,1;0,0) = p(1,1)v - c > p(2,1)v - 2c = u_1(2,1;0,0)$. Thus $(2,1;0,0)$ cannot be an *SPE* either.

This achieves (weak) domination of partial cooperation in the game $\mathcal{G}_N$ by partial cooperation in the game $\mathcal{G}_T$, through elimination of all potential inferior equilibria. Moreover, this is the only overall equilibrium efforts possible in the game $\mathcal{G}_T$.

[**2**] Suppose that $\mathbf{e}_N^* = (2,2)$ (possibly unique). Then in the transparent environment overall efforts of $(2,2)$ can also be supported in an *SPE*. To see this, note that if $\mathbf{e}_N^* = (2,2)$, then for every $\mathbf{e_1} = (e_{11}, e_{21}) \in \mathcal{H}$, the second-round strategy profile $(2 - e_{11}, 2 - e_{21})$ is an *NE* in the continuation game, denoted by $(e_{12}^*(\mathbf{e_1}), e_{22}^*(\mathbf{e_1}))$. Moreover, all strategy profiles $(\mathbf{e_1}; e_{12}^*(\mathbf{e_1}), e_{22}^*(\mathbf{e_1}))$, $\mathbf{e_1} \in \mathcal{H}$, yield:

$$u_i(e_{11}, e_{21}; e_{12}^*(\mathbf{e_1}), e_{22}^*(\mathbf{e_1})) = v - 2c \text{ for } i = 1, 2.$$

Therefore, for each of these strategy profiles, there exists no profitable first-round deviation for any player i, since the payoff to the deviating player is the same as what he receives by not deviating. Thus, full cooperation is an *SPE*. Moreover, by Lemma 3, none of the overall efforts that are inferior to $(2,2)$ can be supported in an *SPE*. Therefore, full cooperation in $\mathcal{G}_N$ is (weakly) dominated by full cooperation as the unique overall equilibrium efforts in the game $\mathcal{G}_T$.

[**3**] Finally, suppose the unique one-shot equilibrium is $\mathbf{e}_N^* = (0,0)$. The following lemma establishes that partial cooperation cannot arise in an *SPE*.

LEMMA A.2. *If* $\mathbf{e}_N^* \neq (1,1)$, *then* $\mathbf{e}_T^* \neq (1,1)$.

PROOF. Online supplementary materials.

However, by Proposition 2[b], full cooperation can arise in equilibrium in the extensive-form game. ■

Proof of Proposition 5. Suppose there are at least two *NE*, $(\tilde{e}_1, \tilde{e}_2)$ and (e_1^*, e_2^*), and $p(\tilde{e}_1, \tilde{e}_2) > p(e_1^*, e_2^*)$. W.l.o.g. assume that $\tilde{e}_2 > e_2^*$. Then we claim that the equilibria can be Pareto-ranked with the players no worse off, and at least one player strictly better off, in equilibrium $(\tilde{e}_1, \tilde{e}_2)$.

By *NE* requirement,

$$[p(\tilde{e}_1, \tilde{e}_2) - p(e_1^*, \tilde{e}_2)]\, v \geq c_1 [\tilde{e}_1 - e_1^*] \tag{A.21}$$

$$[p(\tilde{e}_1, \tilde{e}_2) - p(\tilde{e}_1, e_2^*)]\, v \geq c_2 [\tilde{e}_2 - e_2^*] \tag{A.22}$$

$$[p(e_1^*, e_2^*) - p(\tilde{e}_1, e_2^*)]\, v \geq c_1 [e_1^* - \tilde{e}_1] \tag{A.23}$$

$$[p(e_1^*, e_2^*) - p(e_1^*, \tilde{e}_2)]\, v \geq c_2 [e_2^* - \tilde{e}_2]\,. \tag{A.24}$$

Rewrite (A.21) to obtain:

$$\big[p(\tilde{e}_1, \tilde{e}_2) - p(e_1^*, e_2^*) + \underbrace{p(e_1^*, e_2^*) - p(e_1^*, \tilde{e}_2)}_{<0, \text{ by } \mathbf{A3}}\big] v \geq c_1 \big[\tilde{e}_1 - e_1^*\big]$$

$$\text{or,} \quad [p(\tilde{e}_1, \tilde{e}_2) - p(e_1^*, e_2^*)]\, v > c_1 [\tilde{e}_1 - e_1^*]$$

$$\text{or,} \quad p(\tilde{e}_1, \tilde{e}_2) v - c_1 \tilde{e}_1 > p(e_1^*, e_2^*) v - c_1 e_1^*,$$

which is a strict improvement for player 1.

Next, rewrite (A.22) to obtain:

$$\big[p(\tilde{e}_1, \tilde{e}_2) - p(e_1^*, e_2^*) + p(e_1^*, e_2^*) - p(\tilde{e}_1, e_2^*)\big] v \geq c_2 \big[\tilde{e}_2 - e_2^*\big],$$

which, if $\tilde{e}_1 \geq e_1^*$, implies, by **A3**,

$$\big[p(\tilde{e}_1, \tilde{e}_2) - p(e_1^*, e_2^*)\big] v \geq c_2 \big[\tilde{e}_2 - e_2^*\big],$$

an improvement for player 2. So consider the possibility that $\tilde{e}_1 < e_1^*$. Write

$$\begin{aligned}
\big[p(e_1^*, e_2^*) - p(e_1^*, \tilde{e}_2)\big] v &= -\big[p(e_1^*, \tilde{e}_2) - p(e_1^*, e_2^*)\big] v \\
&< -\big[p(\tilde{e}_1, \tilde{e}_2) - p(\tilde{e}_1, e_2^*)\big] v \quad \text{(by applying } \mathbf{A4}\text{, since } \tilde{e}_2 > e_2^*, \text{ and } \tilde{e}_1 < e_1^*) \\
&\leq -c_2 [\tilde{e}_2 - e_2^*] \qquad \text{(using (A.22))} \\
&= c_2 [e_2^* - \tilde{e}_2]\,,
\end{aligned}$$

violating the *NE* requirement (A.24). Hence, $\tilde{e}_1 < e_1^*$ is ruled out, completing the proof. ■

Proof of Lemma 4. Suppose, contrary to the claim, $\mathbf{e}_N^* = (0,0)$ and $\mathbf{e}_N^* = (1,1)$. Then (refer to Figure 1) it must be that

$$\text{(A.25)} \qquad c \geq (p(1,0) - p(0,0))v$$

$$\text{(A.26)} \qquad \text{and} \qquad c \leq (p(1,1) - p(0,1))v.$$

However, by **A4′**, (A.25) implies that $c > (p(1,1) - p(0,1))v$, contradicting (A.26).

Next, suppose that $\mathbf{e}_N^* = (0,0)$ and $\mathbf{e}_N^* = (2,2)$. This requires that

$$\text{(A.27)} \qquad c \geq [(p(2,0) - p(0,0))v]/2$$

$$\text{(A.28)} \qquad \text{and} \qquad c \leq [(1 - p(0,2))v]/2.$$

Condition (A.27) contradicts (A.28), since by **A4′**, (A.27) implies that $c > [(1-p(0,2))v]/2$.

It is also not possible for $\mathbf{e}_N^* = (1,1)$ and $\mathbf{e}_N^* = (2,2)$ to arise simultaneously. This would require

$$\text{(A.29)} \qquad (p(2,1) - p(1,1))v \leq c$$

$$\text{(A.30)} \qquad \text{and} \qquad c \leq (1 - p(1,2))v,$$

but using **A4′** in (A.29) yields $1 - p(1,2))v < c$, which contradicts (A.30). ■

Proof of Proposition 6. Let e_i denote the aggregate effort of player i in Γ_N, the game under non-transparency. By definition, $\mathbf{e}_N^* = (e_1^*, e_2^*)$ satisfies

$$\text{(A.31)} \qquad p(e_i^*, e_j^*)v - ce_i^* \geq p(e_i, e_j^*)v - ce_i, \quad \forall e_i, \ \forall i.$$

Denote the first-round efforts (e_{11}, e_{21}) in the game with transparency by $\mathbf{e_1}$, and recall that we defined (in section 3) incremental gains from second-round actions (e_{i2}, e_{j2}) given history $\mathbf{e_1}$, as

$$\hat{u}_{i2}(e_{i2}, e_{j2}|\mathbf{e_1}) = u_i(e_{i1} + e_{i2}, e_{j1} + e_{j2}) - \hat{u}_{i1}(e_{i1}, e_{j1}).$$

We now claim that for any *NE* (symmetric or asymmetric) in the non-transparency game, there is a strategy profile in the extensive-form game (under transparency) with the same aggregate efforts that will be an equilibrium in the two-round game. Specifically, for any $\mathbf{e}_N^* = (e_1^*, e_2^*)$, the following strategies form an *SPE* in the extensive form:

1. In the first round, $e_{i1}^* = e_i^*$ for each player i, and

2. In the second round, for $i = 1, 2$,

$$\text{(A.32)} \qquad e_{i2}^* = \begin{cases} 0 & \text{if} \quad \mathbf{e_1} = (e_i^*, \tilde{e}_j); \\ e_i^* - \tilde{e}_i & \text{if} \quad \mathbf{e_1} = (\tilde{e}_i, e_j^*) \text{ and } \tilde{e}_i < e_i^*; \\ e_{i2}^{**} & \text{if} \quad \mathbf{e_1} = (\tilde{e}_i, e_j^*) \text{ and } \tilde{e}_i > e_i^*; \\ \sigma_{i2}^{**} & \text{if} \quad \mathbf{e_1} = (\tilde{e}_i, \tilde{e}_j), \ \tilde{e}_i \neq e_i^*, \text{ and } \ \tilde{e}_j \neq e_j^*, \end{cases}$$

where: $e_{i2}^{**} = \arg\max_{e_{i2} \in \mathbf{E_{i2}}} \ \hat{u}_{i2}(e_{i2}, 0|(\tilde{e}_i, \tilde{e}_j))$, $\mathbf{E_{i2}}$ being player i's set of admissible second-round effort choices, and $j \neq i$ (the solution e_{i2}^{**} exists because the action set is finite); and $(\sigma_{12}^{**}, \sigma_{22}^{**})$ corresponds to some *NE* in the continuation game following the history specified.

Below we verify the Nash equilibrium property of the continuation strategies – both on- and off-the-equilibrium path.

First, consider the second-round strategies $(0, 0)$ following $\mathbf{e_1} = (e_i^*, e_j^*)$. In the second round player j would choose, as specified by (A.32), $e_{j2}^* = 0$, to which we claim that player i's best response is also to set $e_{i2}^* = 0$. To see this, note that i's incremental gain in the second round from choosing $e_{i2} = 0$ is

$$\hat{u}_{i2}(0, 0|(e_i^*, e_j^*)) = \left[p(e_i^* + 0, e_j^* + 0) - p(e_i^*, e_j^*)\right] v - c \times 0,$$

whereas choosing any $e_{i2} > 0$ yields

$$\hat{u}_{i2}(e_{i2}, 0|(e_i^*, e_j^*)) = \left[p(e_i^* + e_{i2}, e_j^* + 0) - p(e_i^*, e_j^*)\right] v - c e_{i2}.$$

Thus,

$$\begin{aligned} \hat{u}_{i2}(0, 0|(e_i^*, e_j^*)) - \hat{u}_{i2}(e_{i2}, 0|(e_i^*, e_j^*)) &= \left[p(e_i^*, e_j^*) - p(e_i^* + e_{i2}, e_j^*)\right] v - c\left[e_i^* - (e_i^* + e_{i2})\right] \\ &\geq 0. \qquad \text{(by (A.31))} \end{aligned}$$

By similar reasoning, $\hat{u}_{j2}(0, 0|(e_i^*, e_j^*)) \geq \hat{u}_{j2}(0, e_{j2}|(e_i^*, e_j^*))$. Therefore, $(0, 0)$ forms an *NE* in the continuation game following $\mathbf{e_1} = (e_i^*, e_j^*)$.

Next, we look at subgames following unilateral deviations. Consider player i's second-round strategy following $\mathbf{e_1} = (\tilde{e}_i, e_j^*)$, where $\tilde{e}_i < e_i^*$, i.e., player i deviates in the first round by reducing e_{i1}. If player j chooses 0, player i cannot do better than to totally make up for his first-round reduction in the second round, that is, choose $e_{i2} = e_i^* - \tilde{e}_i$. We see this by calculating incremental payoffs and then comparing:

$$\begin{aligned}
\hat{u}_{i2}(e_i^* - \tilde{e}_i, 0|(\tilde{e}_i, e_j^*)) &= \left[p(\tilde{e}_i + (e_i^* - \tilde{e}_i), e_j^* + 0) - p(\tilde{e}_i, e_j^*)\right] v - c \times (e_i^* - \tilde{e}_i) \\
&= \left[p(e_i^*, e_j^*) - p(\tilde{e}_i, e_j^*)\right] v - ce_i^* + c\tilde{e}_i, \\
\hat{u}_{i2}(e'_{i2}, 0|(\tilde{e}_i, e_j^*)) &= \left[p(\tilde{e}_i + e'_{i2}, e_j^*) - p(\tilde{e}_i, e_j^*)\right] v - ce'_{i2}, \text{ for } e'_{i2} \neq e_i^* - \tilde{e}_i; \\
\hat{u}_{i2}(e_i^* - \tilde{e}_i, 0|(\tilde{e}_i, e_j^*)) - \hat{u}_{i2}(e'_{i2}, 0|(\tilde{e}_i, e_j^*)) &= \left[p(e_i^*, e_j^*)v - ce_i^*\right] - \left[p(\tilde{e}_i + e_{i2}, e_j^*)v - c \times (\tilde{e}_i + e'_{i2})\right] \\
&\geq 0. \qquad \text{(by (A.31))}
\end{aligned}$$

On the other hand, if player i follows his continuation strategy in (A.32), player j's second-round action $e_{j2} = 0$ is optimal, since for any $e_{j2} > 0$:

$$\begin{aligned}
&\hat{u}_{j2}(e_i^* - \tilde{e}_i, 0|(\tilde{e}_i, e_j^*)) - \hat{u}_{j2}(e_i^* - \tilde{e}_i, e_{j2}|(\tilde{e}_i, e_j^*)) \\
= &\left[p(e_i^*, e_j^*) - p(\tilde{e}_i, e_j^*)\right] v - \left\{\left[p(e_i^*, e_j^* + e_{j2}) - p(\tilde{e}_i, e_j^*)\right] v - ce_{j2}\right\} \\
= &\; p(e_i^*, e_j^*)v - ce_j^* - \left[p(e_i^*, e_j^* + e_{j2})v - ce_j^* - ce_{j2}\right] \\
= &\left[p(e_i^*, e_j^*)v - ce_j^*\right] - \left[p(e_i^*, e_j^* + e_{j2})v - c \times (e_j^* + e_{j2})\right] \\
\geq &\; 0. \qquad \text{(by (A.31))}
\end{aligned}$$

Therefore, the profile $(e_i^* - \tilde{e}_i, 0)$ forms an *NE* in the continuation game following $\mathbf{e_1} = (\tilde{e}_i, e_j^*)$, where $\tilde{e}_i < e_i^*$.

Now consider player i's second-round strategy following $\mathbf{e_1} = (\tilde{e}_i, e_j^*)$, where $\tilde{e}_i > e_i^*$, i.e, player i deviates in the first round by increasing e_{i1}. If player j chooses 0, by construction (and as specified in (A.32)) player i's best response is $e_{i2}^{**} = \max_{e_{i2} \in \mathbf{E_{i2}}} \hat{u}_{i2}(e_{i2}, 0|(\tilde{e}_i, e_j^*))$. On the other hand, if player i follows this strategy then player j's second-round action $e_{j2} = 0$ is optimal. To see this, first note that

$$\begin{aligned}
&\hat{u}_{j2}(e_{i2}^{**}, 0|(\tilde{e}_i, e_j^*)) - \hat{u}_{j2}(e_{i2}^{**}, e_{j2}|(\tilde{e}_i, e_j^*)) \\
= &\left[p(\tilde{e}_i + e_{i2}^{**}, e_j^*) - p(\tilde{e}_i, e_j^*)\right] v - \left\{\left[p(\tilde{e}_i + e_{i2}^{**}, e_j^* + e_{j2}) - p(\tilde{e}_i, e_j^*)\right] v - ce_{j2}\right\} \\
= &\; p(\tilde{e}_i + e_{i2}^{**}, e_j^*)v - ce_j^* - \left[p(\tilde{e}_i + e_{i2}^{**}, e_j^* + e_{j2})v - ce_j^* - ce_{j2}\right] \\
= &\; p(\tilde{e}_i + e_{i2}^{**}, e_j^*) - ce_j^* - \left[p(\tilde{e}_i + e_{i2}^{**}, e_j^* + e_{j2})v - c \times (e_j^* + e_{j2})\right], \quad \text{for any } \; e_{j2} > 0.
\end{aligned}$$

Next, rewrite (A.31) as $p(e_i^*, e_j^*)v - ce_j^* \geq p(e_i^*, e_j)v - ce_j$, $\forall e_j$. This condition implies that for $\tilde{e}_j > e_j^*$,

$$c\tilde{e}_j - ce_j^* \geq \left[p(e_i^*, \tilde{e}_j) - p(e_i^*, e_j^*)\right] v.$$

Therefore,

$$
\begin{aligned}
c\left[e_j^* + e_{j2}\right] - ce_j^* &\geq \left[p(e_i^*, e_j^* + e_{j2}) - p(e_i^*, e_j^*)\right] v \\
&> \left[p(\tilde{e}_i + e_{i2}^{**}, e_j^* + e_{j2}) - p(\tilde{e}_i + e_{i2}^{**}, e_j^*)\right] v \\
&> \left[p(\tilde{e}_i + e_{i2}^{**}, e_j^*) - p(\tilde{e}_i + e_{i2}^{**}, e_j^* + e_{j2})\right] v, \qquad \text{(A.33)}
\end{aligned}
$$

where the second inequality follows from $\mathbf{A4'}$. Using (A.33) we conclude that

$$
\hat{u}_{j2}(e_{i2}^{**}, 0|(\tilde{e}_i, e_j^*)) - \hat{u}_{j2}(e_{i2}^{**}, e_{j2}|(\tilde{e}_i, e_j^*)) > 0, \quad \text{for any } \; e_{j2} > 0.
$$

That is, following the first-round effort profile $(\tilde{e}_i, e_j^*)$ and given player i's second-round action e_{i2}^{**}, player j's best response in the second round is 0. Therefore, the profile $(e_{i2}^{**}, 0)$ forms an *NE* in the continuation game following $\mathbf{e_1} = (\tilde{e}_i, e_j^*)$, $\tilde{e}_i > e_i^*$.

Next, following joint deviations in the first round, $(\sigma_{12}^{**}, \sigma_{22}^{**})$ will be played (as recommended in (A.32)), which by construction is an *NE* in the continuation game.

Let us now return to the first round and consider the overall strategies $(e_i^*, e_j^*; 0, 0)$. This profile yields a payoff to player i of $u_i(e_i^*, e_j^*; 0, 0) = p(e_i^*, e_j^*)v - ce_i^*$. It is clear that there does not exist any profitable unilateral first-round deviation for any player: if i lowers his first-round contribution to $\tilde{e}_i < e_i^*$, he receives $u_i(\tilde{e}_i, e_j^*; e_i^* - \tilde{e}_i, 0) = p(e_i^*, e_j^*)v - ce_i^*$, which is equal to his payoff from not deviating, and if he increases it to $\tilde{e}_i > e_i^*$, he receives $u_i(\tilde{e}_i, e_j^*; e_{i2}^{**}, 0) = p(\tilde{e}_i + e_{i2}^{**}, e_j^*)v - c[\tilde{e}_i + e_{i2}^{**}] \leq p(e_i^*, e_j^*)v - ce_i^*$ (by condition (A.31)); similar argument is applicable to player j. Therefore, $\mathbf{e}_T^* = (e_1^*, e_2^*; 0, 0)$. ■

Proof of Proposition 7. Suppose not so that one of the players, say player 1, would benefit by deviating from the claimed equilibrium strategy under non-transparency. So there must be some $e_1 \neq e_1^*$ such that

$$
\begin{aligned}
u_1(e_1, e_2^*) &> u_1(e_1^*, e_2^*) \\
\text{i.e.,} \qquad p(e_1, e_2^*)v - ce_1 &> p(e_1^*, e_2^*)v - ce_1^*. \qquad \text{(A.34)}
\end{aligned}
$$

Claim 1. $e_1 \geq e_{11}^*$ is not possible.

To see why, let $e_1 = e_{11}^* + e_{12}$ where $e_{12} \in \{0, 1, 2\}$ with the restriction that $e_{12} \leq 2 - e_{11}^*$. Now rewrite (A.34) as:

$$
\begin{aligned}
[p(e_{11}^* + e_{12}, e_{21}^* + e_{22}^*) - p(e_{11}^*, e_{21}^*)]v - ce_{12} &> [p(e_{11}^* + e_{12}^*, e_{21}^* + e_{22}^*) - p(e_{11}^*, e_{21}^*)]v - ce_{12}^*, \\
\text{i.e.,} \qquad \hat{u}_{12}(e_{12}, e_{22}^*|(e_{11}^*, e_{21}^*)) &> \hat{u}_{12}(e_{12}^*, e_{22}^*|(e_{11}^*, e_{21}^*)),
\end{aligned}
$$

but this contradicts the fact that $(e_{11}^*, e_{21}^*; e_{12}^*(e_{11}^*, e_{21}^*), e_{22}^*(e_{11}^*, e_{21}^*))$ is an *SPE* in the extensive-form game under transparency. ||

Next consider the possibility of profitable deviation in the one-shot game (under non-transparency) with $e_1 < e_{11}^*$.

First note that $e_{11}^* \geq 1$, for deviation to a lower effort level to be feasible. Also observe that for the *SPE*, $\mathbf{e}_T^*$, it must be that $e_{22}^* \geq 1$, because otherwise profitable deviation to e_1 in the one-shot game is not consistent with the equilibrium $\mathbf{e}_T^*$. (We write the strategies $\mathbf{e}_T = (e_{11}^*, e_{21}^*; e_{12}^*(e_{11}^*, e_{21}^*), e_{22}^*(e_{11}^*, e_{21}^*))$ as $\mathbf{e}_T^*$.)

Since $(e_{11}^*, e_{21}^*; e_{12}^*(e_{11}^*, e_{21}^*), e_{22}^*(e_{11}^*, e_{21}^*))$ is an *SPE*, the following two best-response conditions will be satisfied:

[1] (**Optimality of Round 2 decisions**) In the second round player 1 will not deviate from his equilibrium effort, that is,

$$
\begin{aligned}
& [p(e_{11}^* + e_{12}^*, e_{21}^* + e_{22}^*) - p(e_{11}^*, e_{21}^*)]v - ce_{12}^* \\
\text{(A.35)} \qquad \geq \; & [p(e_{11}^* + e_{12}, e_{21}^* + e_{22}^*) - p(e_{11}^*, e_{21}^*)]v - ce_{12},
\end{aligned}
$$

for any $0 \leq e_{12} \leq 2 - e_{11}^*$. A similar condition can be stated for player 2.

[2] (**Optimality of Round 1 decisions**) It must be that player 1 will not find deviation by lowering his first-round effort profitable. That is, for any $e_{11} < e_{11}^*$,

$$
\begin{aligned}
& p(e_{11}^* + e_{12}^*, e_{21}^* + e_{22}^*)v - c[e_{11}^* + e_{12}^*] \\
\text{(A.36)} \qquad \geq \; & p(e_{11} + e_{12}^*(e_{11}, e_{21}^*), e_{21}^* + e_{22}^*(e_{11}, e_{21}^*))v - c[e_{11} + e_{12}^*(e_{11}, e_{21}^*)],
\end{aligned}
$$

for all Nash equilibria, $(e_{12}^*(e_{11}, e_{21}^*), e_{22}^*(e_{11}, e_{21}^*))$, in the continuation game following $\mathbf{e_1} = (e_{11}, e_{21}^*)$. Again, a similar condition can be written for player 2.

Following on the optimality of first-round decisions, we further claim:

The *best deviation* payoff for player 1 when he lowers his first-round effort e_{11} below e_{11}^* is *same* as his original *SPE* payoff.

We show this result by establishing the following steps.

First, let player 1, upon deviation in Round 1, increase his second-round effort by $\Delta = e_{11}^* - e_{11} > 0$ to $e_{12}^* + \Delta$, and restore his total efforts to $e_{11} + e_{12}^* + \Delta = e_{11}^* + e_{12}^*$.

Second, with player 1's total efforts equalling e_1^*, player 2's best response in Round 2 continues to be e_{22}^*; this follows from $\mathbf{e}_T$ being *SPE* (i.e., by writing a condition for player 2 similar to (A.35)).

Third, with total efforts by player 2 over the two rounds equalling e_2^* (shown in the second step), below we reconfirm that player 1's best response in Round 2 (after Round 1 deviation to e_{11}) will indeed be to choose $e_{12}^* + \Delta$. To see this, recall (A.35) which can be written as:

$$\begin{aligned}
& [p(e_1^*, e_2^*) - p(e_{11}, e_{21}^*)]v - ce_{12}^* \\
\geq \; & [p(e_{11}^* + e_{12}, e_2^*) - p(e_{11}, e_{21}^*)]v - ce_{12}, \quad \text{for any } \; 0 \leq e_{12} \leq 2 - e_{11}^* \\
\text{i.e.,} \quad & [p(e_1^*, e_2^*) - p(e_{11}, e_{21}^*)]v - c[e_1^* - e_{11}] + c[e_1^* - e_{11} - e_{12}^*] \\
\geq \; & [p(e_{11} + \tilde{e}_{12}, e_2^*) - p(e_{11}, e_{21}^*)]v - c[e_{11} + \tilde{e}_{12} - e_{11}^*], \quad \text{for } \; e_{11} + \tilde{e}_{12} = e_{11}^* + e_{12} \leq 2 \\
\text{i.e.,} \quad & [p(e_1^*, e_2^*) - p(e_{11}, e_{21}^*)]v - c[e_1^* - e_{11}] \\
\geq \; & [p(e_{11} + \tilde{e}_{12}, e_2^*) - p(e_{11}, e_{21}^*)]v - c\tilde{e}_{12} + \{-c[e_{11} - e_{11}^*] - c[e_1^* - e_{11} - e_{12}^*]\}, \\
& \qquad \text{for } \; 0 \leq \tilde{e}_{12} \leq 2 - e_{11}
\end{aligned}$$

$$\text{(A.37)} \quad \text{i.e.,} \quad [p(e_1^*, e_2^*) - p(e_{11}, e_{21}^*)]v - c[e_1^* - e_{11}] \geq [p(e_{11} + \tilde{e}_{12}, e_2^*) - p(e_{11}, e_{21}^*)]v - c\tilde{e}_{12}, \quad \text{for } \; 0 \leq \tilde{e}_{12} \leq 2 - e_{11}.$$

(The last inequality is the optimality of Round 2 decision by player 2 after cutting back on Round 1 effort.)

The second and third steps, together, establish that player 1 choosing $e_{12}^* + \Delta$ and player 2 choosing e_{22}^* form an *NE* in the continuation game following the deviation by player 1 in Round 1.

Now, by (A.38),

$$\begin{aligned}
p(e_1^*, e_2^*)v - c[e_1^* - e_{11}] \;&\geq\; p(e_{11}, e_2^*)v \\
\text{i.e.,} \quad p(e_1^*, e_2^*)v - ce_1^* \;&\geq\; p(e_{11}, e_2^*)v - ce_{11}, \quad \text{for any } \; e_{11} < e_{11}^*,
\end{aligned}$$

contradicting (A.34).

We have thus shown that in the one-shot game under non-transparency, if player 2 chooses e_2^* then deviation by player 1 (as in (A.34)) is not possible. Similarly, if player 1 chooses e_1^*, deviation by player 2 is not possible. Thus, (e_1^*, e_2^*) is an *NE* under non-transparency. ■

Supplementary materials

The manuscript contains additional supplementary materials.

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