Bonn Econon Discussion Papers

Discussion Paper 03/2014

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December 2014

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Financial support by the
Deutsche Forschungsgemeinschaft (DFG)
through the
Bonn Graduate School of Economics (BGSE)
is gratefully acknowledged.

Deutsche Post World Net is a sponsor of the BGSE.

Peer Effects and Incentives*

Matthias Kräkel†

Abstract

In a multi-agent setting, individuals often compare own performance with that of their peers. These comparisons influence agents' incentives and lead to a noncooperative game, even if the agents have to complete independent tasks. I show that depending on the interplay of the peer effects, agents' efforts are either strategic complements or strategic substitutes. I solve for the optimal monetary incentives that complement the peer effects and show that the principal prefers sequential effort choices of the agents to choosing efforts simultaneously.

Keywords: externalities; moral hazard; other-regarding preferences.

JEL Classification: C72; D03; D86.

*Financial support by the Deutsche Forschungsgemeinschaft (DFG), grant SFB/TR 15 ("Governance and the Efficiency of Economic Systems"), is gratefully acknowledged.

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"“pure” peer effects refer to a situation where workers work, side by side, for the same firm but do not interact in any way (except that they observe each others’ work activity)"

(Charness and Kuhn 2011, p. 255)

1 Introduction

Real agents typically compare their economic outcomes with one another and have – to some extent – so-called social or other-regarding preferences. Theories on these preferences assume that the agents compare their incomes or payoffs (Fehr and Schmidt 1999, Bolton and Ockenfels 2000, Charness and Rabin 2002, Fershtman et al. 2003). However, in practice, agents often do not know the *incomes* or *payoffs* of their peers but mutually observe each other’s *performance*.[1] Empirical studies show that this performance information strongly influences workers’ effort choices (Falk and Ichino 2006, Mas and Moretti 2009, Gächter et al. 2013, Georganas et al. 2013). From a theoretical perspective, such peer effects have to be kept in mind by a principal when designing optimal incentives in a multi-agent setting.

In this note, I analyze the interplay of incentives arising from peer effects and corresponding optimal monetary incentives. Following the observations by Sheremeta (2010) and Dohmen et al. (2011), I model peer effects as additional utility or disutility arising from the mere fact of outperforming one’s peer or being outperformed by the peer, respectively. In the first case, we can also speak of positive externalities and in the latter case of negative externalities that an agent receives from comparing own performance with peer performance.

My analysis shows that, even if the agents have to complete independent tasks, peer effects will lead to a game between the agents, which the princi-

[1] Charness et al. (2014) report that, even if agents lack this performance information and if their compensation does not depend on their peers’ output, firms nevertheless provide agents with relative performance information.

pal has to anticipate when designing optimal incentives. Depending on the magnitude of the externalities arising from peer effects, agents' efforts are either strategic substitutes or strategic complements in the notion of Bulow et al. (1985).

First, I consider a situation in which the principal does not face restrictions on the optimal contract choice. If peer effects are quite strong for one agent and rather weak for the other, the principal will implement excessive effort by the former agent and little effort by the latter. Otherwise, the principal is confronted with a kind of coordination problem: (i) If negative externalities dominate positive ones, the principal will prefer either excessive efforts by both agents or little efforts by both agents to prevent that one of the agents outperforms his peer. (ii) If positive externalities dominate negative ones, the principal will prefer excessive effort by one of the agents and little effort by the other to generate a net gain in terms of externalities.

If the principal's contracting space is restricted to non-negative wages (limited liability) and the agents earn positive rents, peer effects will unambiguously benefit the principal. He particularly profits from large negative externalities, which make efforts be strategic complements so that incentives for one agent spill over to his peer. Finally, if the principal can choose between agents moving simultaneously or sequentially, he will strictly prefer a sequential-move setting.

Peer effects crucially differ from preferences based on relative income, like inequity aversion introduced by Fehr and Schmidt (1999). As Englmaier and Wambach (2010) show, if inequity aversion is sufficiently strong, the principal will prefer team compensation despite independent tasks to eliminate inequity costs, which contradicts the informativeness principle of Holmstrom (1979). I show that in case of peer effects, however, the informativeness principle always applies and optimal incentives can be solely based on individual performance although agents' efforts are mutually influenced by positive and negative externalities.

I start the analysis with a basic moral-hazard model that considers optimal incentives without restricting the set of feasible contracts. Thereafter, I successively skip two main assumptions – unlimited liability and simultaneous moves of the agents.

2 The Basic Model

I consider a situation in which a principal, P, has to hire two agents, A and B, in order to run a business.[2] All parties are risk-neutral. A and B have zero reservation values. When working for P, agent i $(i = A, B)$ exerts effort $e_i \in [0, 1]$ to generate a return $R_i \in \{0, R\}$ for P. As an example, we can think of a sales agent that either acquires a new customer or not. Alternatively, imagine a researcher that either succeeds in publishing in one of the top journals or not. With probability $\Pr(R_i = R|e_i) = e_i$ agent i is successful and generates the high return $R > 0$ and with probability $1 - e_i$ the agent fails and realizes 0. The realization of R_i is verifiable, but P cannot observe e_i (moral hazard). Effort e_i entails costs on agent i being described by the function c_i with the usual technical characteristics $c_i'(e_i), c_i''(e_i) > 0$, $c_i'''(e_i) \geq 0$ for $e_i > 0$, and $c_i(0) = c_i'(0) = 0$, $c_i'(1) \geq R$.

I deviate from the textbook moral-hazard model by assuming peer effects between the agents, who both observe R_A and R_B. If agent i is more successful than agent j, there will be a negative and a positive externality: i's payoff is enlarged by $\alpha_i > 0$, whereas j's payoff is reduced by $\beta_j > 0$. If both agents' performance is the same (i.e., $R_A = R_B$), there will be no externalities. Let $\Psi := \beta_A + \beta_B - \alpha_A - \alpha_B \neq 0$ so that externalities do not cancel each other out, and $\inf_{e_A, e_B} c_A''(e_A) c_B''(e_B) > \Psi^2$ to guarantee that P's objective

[2] The main assumptions follow the single-agent setting of Schmitz (2005) and Ohlendorf and Schmitz (2012). Externalities are modeled similar to emotional effects that are considered by Kräkel (2008a, 2008b) in connection with linear contracts and tournament contracts.

function is well-behaved.[3] The timing of the game is as follows. First, P offers contracts to A and B. Then, A and B decide whether to accept the offers. In case of acceptance, A and B simultaneously choose efforts. Finally, returns are realized and the agents receive their contracted payments.

3 Solution to the Basic Model

Let us denote those efforts that maximize material welfare $R \cdot e_A + R \cdot e_B - c_A(e_A) - c_B(e_B)$ by $\hat{e}_i$ $(i = A, B)$, being implicitly described by $R = c_i'(\hat{e}_i)$. In the following, these efforts serve as a benchmark solution, because P would implement $\hat{e}_i$ in the absence of peer effects.

Although agents' efforts are mutually influenced by the externalities α_i and β_i, the informativeness principle of Holmstrom (1979) applies and I can focus on contracts that reward each agent based on own individual performance.[4] Thus, the set of contracts offered to agent i is described by (w_1^i, w_0^i) with wage w_1^i (w_0^i) being paid to i in case of $R_i = R$ $(R_i = 0)$. Given that both agents have accepted their contract offers, i $(i = A, B)$ maximizes

$$e_i[e_j w_1^i + (1-e_j)\left(w_1^i + \alpha_i\right)] + (1-e_i)\left[e_j\left(w_0^i - \beta_i\right) + (1-e_j)\, w_0^i\right] - c_i(e_i)\,. \quad (1)$$

As the objective function is strictly concave, i's optimal effort is described by the first-order condition:

$$\beta_i e_j + (1-e_j)\,\alpha_i + \Delta w^i = c_i'(e_i) \qquad \text{with } \Delta w^i := w_1^i - w_0^i. \quad (2)$$

(2) points out that the existence of peer effects leads to a game between A and B although the agents perform independent tasks. In particular, if $\beta_i > (<)\alpha_i$ $(i = A, B)$, agents' efforts will be strategic complements (substitutes) in

[3] E.g., if both agents have quadratic costs $\frac{\kappa}{2}e_i^2$, the condition yields $\kappa^2 > \Psi^2$.

[4] Intuitively, agents' tasks are technologically and stochastically independent and the payoff components α_i and β_i cannot be influenced by the contract design. See the Additional Material for the Referees, Part A, for a formal proof.

the notion of Bulow et al. (1985). Eq. (2) also shows that incentives arise for three reasons. The wage spread Δw^i indicates standard textbook incentives. $(1 - e_j)\,\alpha_i$ characterizes i's additional incentives from peer effects conditional on j being unsuccessful – i wants to benefit from positive externalities – and $\beta_i e_j$ additional peer incentives conditional on j being successful – i wants to avoid negative externalities.

At the contracting stage, P offers (w_1^i, w_0^i) $(i = A, B)$ to maximize expected profits $Re_A + Re_B - e_A \Delta w^A - w_0^A - e_B \Delta w^B - w_0^B$ subject to the incentive constraints (2) and the participation constraints that (1) is non-negative. Let $\bar{e}_i := (\beta_i - \alpha_j)/\Psi$ $(i, j = A, B;\ i \neq j)$. Then, the following result is obtained:[5]

Proposition 1 *P implements the following e_i^* and e_j^* $(i, j = A, B;\ i \neq j)$:*
(a) if $\beta_i < \alpha_j$ and $\beta_j > \alpha_i$, then $e_i^* < \hat{e}_i$ and $e_j^* > \hat{e}_j$,
(b) if $\beta_i > \alpha_j$ and $\beta_j > \alpha_i$, then $e_i^* \gtreqless \hat{e}_i$ iff $e_j^* \gtreqless \bar{e}_j$,
(c) if $\beta_i < \alpha_j$ and $\beta_j < \alpha_i$, then $e_i^* \gtreqless \hat{e}_i$ iff $e_j^* \lesseqgtr \bar{e}_j$.

Proposition 1 compares the efforts that are implemented by P in the presence of peer effects with those efforts that maximize material welfare and, hence, would be implemented without peer effects. Result (a) shows that if for one agent positive (negative) externalities from peer effects are larger than the negative (positive) externalities for the other agent, P will prefer excessive effort by the former one and little effort by the latter. The intuition is the following. Since agents are not protected by limited liability, the agents' participation constraints will be binding under the optimal contracts. As a consequence, P is the party that actually benefits from positive externalities and suffers from negative ones. If $\beta_i < \alpha_j$ and $\beta_j > \alpha_i$, P is mainly interested in agent j outperforming agent i and preventing i from outperforming j.

Result (b) deals with the case where the negative externalities of each agent exceed the positive externalities of the respective other agent. In that

[5] All proofs are relegated to the appendix.

situation, P has to solve a coordination problem to prevent that the agents' realized returns R_A and R_B differ. Either both agents should choose high efforts so that they both succeed with high probability, or both agents should choose low efforts so that both fail with high probability.

Result (c) addresses the opposite case where the positive externalities of each agent exceed the negative externalities of the respective other agent. Now, P faces a reversed coordination problem: One of the agents should choose high effort and the other one low effort so that P realizes the net benefit $\alpha_A - \beta_B$ or $\alpha_B - \beta_A$, respectively. Altogether, the results of Proposition 1 highlight that the design of optimal incentives becomes more complex in the presence of peer effects because now P has to control a game between the agents. If peer effects are sufficiently strong, it can be even optimal to implement excessive effort solely for that agent whose cost-of-effort function is steeper than that of his peer.

When comparing P's expected profits with and without peer effects, the following result is obtained:

Proposition 2 *(a) If $\beta_i > (<) \alpha_j$ $(i, j = A, B;\ i \neq j)$, the principal will suffer (benefit) from peer effects. (b) If $\beta_i > \alpha_i$ $(i = A, B)$, the principal can still benefit from peer effects.*

Result (a) is straightforward. Since, under the optimal contracts, the agents' participation constraints are binding, P will suffer (benefit) if the negative externalities from peer effects are large (small) compared to the positive externalities. However, result (b) is all the more surprising. It shows that P can be better off by the existence of peer effects if each agent's negative externalities exceed his positive externalities. This counterintuitive result can be explained as follows. Suppose that P wants to implement $e_A < e_B$. Hence, it is more likely that B instead of A is successful. If this effect sufficiently relaxes B's participation constraint because $\alpha_B - \alpha_A > 0$

is quite large, the overall effect on profits can be positive despite $\beta_i > \alpha_i$ $(i = A, B)$. Note that the constellation $\alpha_B > \beta_A > \alpha_A$ is feasible so that P will benefit from peer effects if the probability for B outperforming A is quite high and $\alpha_B - \beta_A$ is quite large.

4 Wealth-Constrained Agents

The basic model does not impose any restriction on feasible wages. This section considers the case that both agents are wealth-constrained so that wages are not allowed to be negative. Depending on the magnitude of the agents' externalities, the participation constraints may be binding or not in the optimum. In the following, I focus on the more interesting case where the constraints do not bind so that the agents earn positive rents. Again, the informativeness principle applies.[6]

Proposition 3 *Suppose A and B are wealth-constrained and earn positive rents. (a) P implements e_A^* and e_B^* being described by $R + \Psi e_j^* + \alpha_i = c_i'(e_i^*) + e_i^* c_i''(e_i^*)$ $(i, j = A, B; A \neq B)$. (b) There exists a cut-off value $\bar{\Psi} > 0$ so that $e_i^* > \hat{e}_i$ if $\Psi > \bar{\Psi}$. (c) P strictly benefits from peer effects.*

Proposition 3 addresses a situation in which agents are protected by limited liability and earn positive rents. In such scenario, the principal is primarily interested in the incentive properties of peer effects, because the participation constraint is non-binding. P will strictly profit if peer effects boost incentives, since he does not have to compensate the agents for the negative externalities β_i, which only reduce agents' rents. The incentive constraints (2) show that both kinds of externalities increase agents' incentives – each agent i chooses high effort to benefit from positive externalities α_i and to avoid negative externalities β_i, which explains result (c).

Results (a) and (b) emphasize the importance of Ψ in the given situation. Result (a) implies that, if $\Psi > 0$, P will implement higher efforts

[6] See the Additional Material for the Referees, Part B.

with peer effects than without. If, moreover, Ψ is sufficiently large, implemented efforts under peer effects will exceed efforts that maximize material welfare (result (b)). The intuition for both findings can be best explained by considering the incentive constraints (2). According to (2), efforts will be strategic complements in the notion of Bulow et al. (1985) if each agent's negative externalities are stronger than positive ones (i.e., $\beta_i > \alpha_i$). Intuitively, if $\beta_i > \alpha_i$, agent i is mainly interested not to be outperformed by his peer, because i would strongly suffer from the negative externalities. Consequently, if j chooses high effort, i should choose high effort as well so that a tie $R_j = R_i = R$ occurs with high probability, which would eliminate β_i. If, on the contrary, j chooses low effort and most probably fails, then it is optimal for i to choose low effort as well since the probability of being outperformed by j is rather low and the extra utility from outperforming j is not very large. P benefits from strategic complements, because incentivizing one agent leads to additional incentives for his peer and because these additional incentives are free for P, as argued in the paragraph before. Note that efforts being strategic complements (i.e., $\beta_i > \alpha_i$) is a sufficient condition for $\Psi := \beta_A + \beta_B - \alpha_A - \alpha_B > 0$, which completes the intuition.

Recall that P tends to suffer from high values of β_i in case of binding participation constraints, since he has to compensate the agents for receiving negative externalities. However, as Proposition 3 shows, the situation will be completely different, if agents earn positive rents. Now P strictly benefits from negative externalities.

5 Sequential Moves

In the basic model, agents are assumed to choose efforts simultaneously. In this section, I skip this assumption to analyze whether peer effects have a higher impact when agents move sequentially. Let, w.l.o.g., agent A be the first mover and agent B the follower, i.e., first A chooses e_A and the two agents and P observe R_A, thereafter B chooses e_B and R_B is realized.

Since R_A is verifiable, P can make B's payment contingent on A's performance. Such contingent contracts might be useful in the given situation, because B's behavior is influenced by peer effects and, thus, depends on whether $R_A = R$ or $R_A = 0$. Hence, P offers two sorts of contracts. A is again offered $\left(w_1^A, w_0^A\right)$,[7] but B gets the contract offer $\left(w_0^B\left(R_A\right), w_1^B\left(R_A\right)\right)$ with wage spread $\Delta w^B\left(R_A\right) := w_1^B\left(R_A\right) - w_0^B\left(R_A\right)$. The game is solved backwards. If $R_A = R$, then B maximizes

$$w_1^B\left(R\right) e_B + \left(w_0^B\left(R\right) - \beta_B\right)\left(1 - e_B\right) - c_B\left(e_B\right),$$

and if $R_A = 0$, B maximizes

$$\left(w_1^B\left(0\right) + \alpha_B\right) e_B + w_0^B\left(0\right)\left(1 - e_B\right) - c_B\left(e_B\right).$$

Therefore, B's optimal effort is

$$e_B\left(R_A\right) = \begin{cases} p_B\left(\Delta w^B\left(R\right) + \beta_B\right) & \text{if} \quad R_A = R \\ p_B\left(\Delta w^B\left(0\right) + \alpha_B\right) & \text{if} \quad R_A = 0 \end{cases} \tag{3}$$

with p_B denoting the inverse of the marginal cost function c_B'. Agent A anticipates $e_B\left(R_A\right)$ and maximizes

$$e_A p_B\left(\Delta w^B\left(R\right) + \beta_B\right) w_1^A + e_A\left[1 - p_B\left(\Delta w^B\left(R\right) + \beta_B\right)\right]\left(w_1^A + \alpha_A\right) - c_A\left(e_A\right)$$
$$+ \left(1 - e_A\right) p_B\left(\Delta w^B\left(0\right) + \alpha_B\right)\left(w_0^A - \beta_A\right) + \left(1 - e_A\right)\left[1 - p_B\left(\Delta w^B\left(0\right) + \alpha_B\right)\right] w_0^A.$$

Thus, agent A's optimal effort, e_A, is implicitly described by

$$\Delta w^A + \alpha_A + p_B\left(\Delta w^B\left(0\right) + \alpha_B\right)\beta_A - p_B\left(\Delta w^B\left(R\right) + \beta_B\right)\alpha_A = c_A'\left(e_A\right). \tag{4}$$

[7] Making A's payment contingent on R_B does not make sense, because A cannot react to the realization of R_B ex post.

P anticipates $e_B(R_A)$ and e_A, and chooses the optimal contracts. Comparing expected profits in the simultaneous-move setting with those in the sequential-move setting leads to a clear-cut result:

Proposition 4 *If P can choose between a simultaneous-move and a sequential-move setting, he will strictly prefer the latter one.*

The proof of Proposition 4 shows that, when agents move sequentially, P could implement the same efforts as in the simultaneous-move setting, but he strictly prefers other effort levels: If e_B^* denotes B's optimal effort in the simultaneous-move case, in the sequential-move setting P will implement $e_B(R)$ and $e_B(0)$ with

$$e_B(R) \gtreqless e_B^* \gtreqless e_B(0) \Leftrightarrow \beta_B - \alpha_A \gtreqless \alpha_B - \beta_A.$$

Intuitively, P benefits from the fact that he can choose state-dependent incentives via $\Delta w^B(R)$ and $\Delta w^B(0)$ compared to the simultaneous-move case, where all incentives have to be designed in a purely probabilistic environment. As an example, suppose that $\beta_B - \alpha_A > \alpha_B - \beta_A > 0$, which corresponds to the constellation $e_B(R) > e_B^* > e_B(0)$. Thus, B's peer effects are stronger than A's so that – due to the binding participation constraints – P's relative loss from the negative externalities received by B (i.e., $\beta_B - \alpha_A$) exceeds P's relative gain from positive externalities received by B (i.e., $\alpha_B - \beta_A$). In this situation, it is most important for P to avoid an outcome where A succeeds and B fails. Therefore, if A is successful ($R_A = R$), then the induced effort to agent B, $e_B(R)$, should be very high and larger than B's effort given that A has failed, $e_B(0)$.

Appendix

Proof of Proposition 1:

The agents' participation constraints can be rewritten as

$$e_i e_j (\beta_i - \alpha_i) + e_i \alpha_i - e_j \beta_i - c_i (e_i) \geq -e_i \Delta w^i - w_0^i.$$

When considering P's objective function and the incentive constraints (2), we can see that, under the optimal contracts, P uses Δw^i to implement the preferred effort levels and w_0^i to extract all worker rents. In other words, since both incentives and expected profits decrease in w_0^i, P chooses w_0^i to make the participation constraints just bind. Inserting $-e_i \Delta w^i - w_0^i = e_i e_j (\beta_i - \alpha_i) + e_i \alpha_i - e_j \beta_i - c_i (e_i)$ into P's objective function yields

$$Re_A + Re_B + e_A e_B \Psi + e_A (\alpha_A - \beta_B) + e_B (\alpha_B - \beta_A) - c_A (e_A) - c_B (e_B) . \quad (5)$$

Because the technical assumption $\inf_{e_A, e_B} c_A'' (e_A) c_B'' (e_B) > \Psi^2$ guarantees that the second-order conditions $-c_i'' (e_i^*) < 0$ $(i = A, B)$ and $c_A'' (e_A^*) c_B'' (e_B^*) > \Psi^2$ hold, optimal efforts are described by the first-order conditions $R + e_j \Psi + \alpha_i - \beta_j = c_i' (e_i)$ $(i, j = A, B; i \neq j)$. Recall that $\hat{e}_i$ is defined by $R = c_i' (\hat{e}_i)$. If $\beta_i < \alpha_j$ and $\beta_j > \alpha_i$, then $e_j \Psi + \alpha_i - \beta_j = -e_j (\alpha_j - \beta_i) - (1 - e_j) (\beta_j - \alpha_i) < 0$ and $e_i \Psi + \alpha_j - \beta_i = e_i (\beta_j - \alpha_i) + (1 - e_i) (\alpha_j - \beta_i) > 0$ so that $e_i^* < \hat{e}_i$ and $e_j^* > \hat{e}_j$, which proves result (a).

Let $\beta_i > \alpha_j$ and $\beta_j > \alpha_i$. Then, $\Psi > 0$, and $e_i^* \gtreqless \hat{e}_i$ if and only if $e_j^* \Psi + \alpha_i - \beta_j \gtreqless 0 \Leftrightarrow e_j^* \gtreqless (\beta_j - \alpha_i) / \Psi$, which proves (b).

Let $\beta_i < \alpha_j$ and $\beta_j < \alpha_i$. Then, $\Psi < 0$, and $e_i^* \gtreqless \hat{e}_i$ if and only if $e_j^* \Psi + \alpha_i - \beta_j \gtreqless 0 \Leftrightarrow e_j^* \lesseqgtr (\beta_j - \alpha_i) / \Psi$, which proves (c).

Proof of Proposition 2:

Under peer effects, P can implement the same effort levels as in the situation without peer effects by choosing Δw^A and Δw^B appropriately so that $\beta_i e_j +$

$(1-e_j)\,\alpha_i + \Delta w^i = R$ for $i, j = A, B$; $i \neq j$ (see (2)). Then, (5) shows that P will prefer (dislike) peer effects if

$$\hat{e}_A \hat{e}_B \Psi + \hat{e}_A(\alpha_A - \beta_B) + \hat{e}_B(\alpha_B - \beta_A) > (<) 0 \Leftrightarrow$$
$$\hat{e}_A(1-\hat{e}_B)(\alpha_A - \beta_B) + \hat{e}_B(1-\hat{e}_A)(\alpha_B - \beta_A) > (<) 0,$$

which proves result (a).

Now, consider (b). Define $\Delta_A := \beta_A - \alpha_A > 0$ and $\Delta_B := \beta_B - \alpha_B > 0$, and suppose that P again implements $\hat{e}_A$ and $\hat{e}_B$. Then, P will profit from peer effects if

$$\hat{e}_A \hat{e}_B \Psi + \hat{e}_A(\alpha_A - \beta_B) + \hat{e}_B(\alpha_B - \beta_A) > 0 \Leftrightarrow$$
$$-(1-\hat{e}_A)\,\hat{e}_B \Delta_A - (1-\hat{e}_B)\,\hat{e}_A \Delta_B + (\hat{e}_B - \hat{e}_A)(\alpha_B - \alpha_A) > 0.$$

Let, w.l.o.g., c_A be steeper than c_B implying $\hat{e}_B > \hat{e}_A$. Furthermore, let $\alpha_B - \alpha_A > 0$. Then, there exist upper bounds $\bar{\Delta}_i$ $(i = A, B)$ so that $(\hat{e}_B - \hat{e}_A)(\alpha_B - \alpha_A) > (1-\hat{e}_A)\,\hat{e}_B \Delta_A + (1-\hat{e}_B)\,\hat{e}_A \Delta_B$ for all $\Delta_i < \bar{\Delta}_i$ $(i = A, B)$.

Proof of Proposition 3:

(a) In the given situation with $w_0^i, w_1^i \geq 0$ and positive rents, wages $w_0^A = w_0^B = 0$ are optimal so that P maximizes $R \cdot (e_A + e_B) - e_A w_1^A - e_B w_1^B$ subject to the incentive constraints $\beta_i e_j + (1-e_j)\,\alpha_i + w_1^i = c_i'(e_i)$. Thus, P implements efforts e_A^* and e_B^* that maximize

$$e_A\left[R + \beta_A e_B + (1-e_B)\,\alpha_A - c_A'(e_A)\right] + e_B\left[R + \beta_B e_A + (1-e_A)\,\alpha_B - c_B'(e_B)\right]. \tag{6}$$

The first-order conditions $R + e_j^* \Psi + \alpha_i = c_i'(e_i^*) + e_i^* c_i''(e_i^*)$ $(i, j = A, B; A \neq B)$ will describe the optimal effort levels, if the second-order conditions hold. These are given by $-2c_i''(e_i^*) - e_i^* c_i'''(e_i^*) < 0$ $(i = A, B)$ and $(2c_A''(e_A^*) +$

$e_A^* c_A''' (e_A^*))(2c_B'' (e_B^*) + e_B^* c_B''' (e_B^*)) > \Psi^2$, where the last condition holds due to the technical assumptions $\inf_{e_A, e_B} c_A'' (e_A) c_B'' (e_B) > \Psi^2$ and $c_i''' (e_i) \geq 0$.

(b) Recall that I consider a situation in which we can ignore the participation constraints and focus on the agents' incentives. Define the system of equations $F^i := R + \Psi e_j^* + \alpha_i - c_i' (e_i^*) - e_i^* c_i'' (e_i^*)$ (with $i, j = A, B; A \neq B$) for doing comparative statics via the implicit-function theorem. The corresponding Jacobian determinant

$$|J| = \begin{vmatrix} \frac{\partial F^A}{\partial e_A^*} & \frac{\partial F^A}{\partial e_B^*} \\ \frac{\partial F^B}{\partial e_A^*} & \frac{\partial F^B}{\partial e_B^*} \end{vmatrix} = \begin{vmatrix} -2c_A'' (e_A^*) - e_A^* c_A''' (e_A^*) & \Psi \\ \Psi & -2c_B'' (e_B^*) - e_B^* c_B''' (e_B^*) \end{vmatrix}$$
$$= (2c_A'' (e_A^*) + e_A^* c_A''' (e_A^*)) (2c_B'' (e_B^*) + e_B^* c_B''' (e_B^*)) - \Psi^2$$

is strictly positive as we know from the proof of result (a). Then, given $\Psi > 0$,

$$\frac{\partial e_A^*}{\partial \Psi} = \frac{1}{|J|} \begin{vmatrix} -\frac{\partial F^A}{\partial \Psi} & \frac{\partial F^A}{\partial e_B^*} \\ -\frac{\partial F^B}{\partial \Psi} & \frac{\partial F^B}{\partial e_B^*} \end{vmatrix} = \frac{(2c_B'' (e_B^*) + e_B^* c_B''' (e_B^*)) e_B^* + e_A^* \Psi}{|J|} > 0$$

and, analogously, $\frac{\partial e_B^*}{\partial \Psi} = [(2c_A'' (e_A^*) + e_A^* c_A''' (e_A^*)) e_A^* + e_B^* \Psi] / |J| > 0$. Thus, if $\Psi > 0$ is sufficiently large, implemented efforts under peer effects will exceed the efforts that maximize material welfare.

(c) In principle, P could implement the same effort levels as in the situation without peer effects. From (6) we can see that P then unambiguously benefits from peer effects, since $\beta_A e_A e_B + e_A (1 - e_B) \alpha_A + \beta_B e_A e_B + e_B (1 - e_A) \alpha_B > 0$.

Proof of Proposition 4:

Similar to the basic model, the agents' participation constraints will be binding under the optimal contracts:

$$e_A \left[e_B(0)\beta_A - e_B(R)\alpha_A\right] + e_A\alpha_A - e_B(0)\beta_A - c_A(e_A) = -e_A\Delta w^A - w_0^A$$

and

$$\begin{aligned}
&e_A \left[e_B(R)\beta_B - e_B(0)\alpha_B\right] + e_B(0)\alpha_B - e_A\beta_B - e_A c_B(e_B(R)) - (1-e_A)c_B(e_B(0)) \\
&= -e_A e_B(R)\Delta w^B(R) - (1-e_A)e_B(0)\Delta w^B(0) - (1-e_A)w_0^B(0) - e_A w_0^B(R)
\end{aligned}$$

with $e_B(0) = p_B\left(\Delta w^B(0) + \alpha_B\right)$ and $e_B(R) = p_B\left(\Delta w^B(R) + \beta_B\right)$. Inserting the binding constraints in P's objective function,

$$\begin{aligned}
&R\left[e_A + e_A e_B(R) + (1-e_A)e_B(0)\right] - e_A w_1^A - (1-e_A)w_0^A \\
&- e_A e_B(R) w_1^B(R) - (1-e_A)e_B(0) w_1^B(0) \\
&- e_A(1-e_B(R)) w_0^B(R) - (1-e_A)(1-e_B(0)) w_0^B(0),
\end{aligned}$$

yields

$$\begin{aligned}
&R\left[e_A + e_A e_B(R) + (1-e_A)e_B(0)\right] + e_A(\alpha_A - \beta_B) + e_B(0)\left[\alpha_B - \beta_A\right] \\
&+ e_A\left[e_B(0)\beta_A + e_B(R)\beta_B - e_B(R)\alpha_A - e_B(0)\alpha_B\right] \qquad (7) \\
&- c_A(e_A) - e_A c_B(e_B(R)) - (1-e_A)c_B(e_B(0)).
\end{aligned}$$

P can implement any efforts he like by appropriately choosing the wage spreads $\Delta w^B(R)$, $\Delta w^B(0)$, and Δw^A in the incentive constraints (3) and (4). In particular, P can implement $e_B(R) = e_B(0)$ so that his objective functions for the simultaneous-move setting (i.e., (5)) and the sequential-move setting (i.e., (7)) coincide. Thus, letting agents move sequentially instead of simultaneously cannot be detrimental for P. However, it can be shown that P *strictly* prefers $e_B(R) \neq e_B(0)$, implying that P is better off in the sequential-move setting: The first-order conditions[8] for the optimal efforts $e_B^*(R)$ and $e_B^*(0)$ lead to a unique solution being implicitly described by $R + \beta_B - \alpha_A = c_B'(e_B^*(R))$ and $R + \alpha_B - \beta_A = c_B'(e_B^*(0))$. Hence, $e_B^*(R) \neq e_B^*(0)$ because $\beta_B - \alpha_A \neq \alpha_B - \beta_A \Leftrightarrow \Psi \neq 0$ is true.

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[8] See the Additional Material for the Referees, Part C.

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Additional pages for the referees

Part A: Validity of the Informativeness Principle in the Basic Model

Suppose P uses both R_A and R_B to generate incentives for each agent. Let w_{11}^i denote agent i's wage if both agents are successful and realize R, w_{10}^i (w_{01}^i) the wage of agent i if i succeeds and j fails (if i fails and j succeeds), and w_{00}^i agent i's wage if both fail. Then, agent A maximizes

$$EU_A = e_A[e_B w_{11}^A + (1-e_B)\left(w_{10}^A + \alpha_A\right)] + (1-e_A)\left[e_B\left(w_{01}^A - \beta_A\right) + (1-e_B)\, w_{00}^A\right] - c_A\left(e_A\right)$$

and agent B

$$EU_B = e_B[e_A w_{11}^B + (1-e_A)\left(w_{10}^B + \alpha_B\right)] + (1-e_B)\left[e_A\left(w_{01}^B - \beta_B\right) + (1-e_A)\, w_{00}^B\right] - c_B\left(e_B\right).$$

The first-order conditions yield the following incentive constraints:

$$e_B\left(\left[w_{11}^A - w_{10}^A\right] - \left[w_{01}^A - w_{00}^A\right] + \beta_A - \alpha_A\right) + \left[w_{10}^A - w_{00}^A\right] + \alpha_A = c_A'\left(e_A\right) \tag{8}$$

$$e_A\left(\left[w_{11}^B - w_{10}^B\right] - \left[w_{01}^B - w_{00}^B\right] + \beta_B - \alpha_B\right) + \left[w_{10}^B - w_{00}^B\right] + \alpha_B = c_B'\left(e_B\right). \tag{9}$$

The agents' participation constraints $EU_A \geq 0$ and $EU_B \geq 0$ can be rewritten as

$$\begin{aligned} &e_A e_B\left[w_{11}^A - w_{10}^A\right] + (1-e_A)\, e_B\left[w_{01}^A - w_{00}^A\right] + e_A\left(w_{10}^A - w_{00}^A\right) + w_{00}^A \\ &\quad + e_A\left(1-e_B\right)\alpha_A - \left(1-e_A\right) e_B \beta_A - c_A\left(e_A\right) \geq 0 \end{aligned} \tag{10}$$

and

$$e_B e_A\left[w_{11}^B-w_{10}^B\right]+\left(1-e_B\right)e_A\left[w_{01}^B-w_{00}^B\right]+e_B\left[w_{10}^B-w_{00}^B\right]+w_{00}^B$$
$$+e_B\left(1-e_A\right)\alpha_B-\left(1-e_B\right)e_A\beta_B-c_B\left(e_B\right)\geq 0. \tag{11}$$

P maximizes

$$Re_A+Re_B-e_A e_B\left(w_{11}^A+w_{11}^B\right)-e_A\left(1-e_B\right)\left(w_{10}^A+w_{01}^B\right)$$
$$-\left(1-e_A\right)e_B\left(w_{01}^A+w_{10}^B\right)-\left(1-e_A\right)\left(1-e_B\right)\left(w_{00}^A+w_{00}^B\right)\Leftrightarrow$$

$$\begin{aligned}&Re_A+Re_B \qquad (12)\\&-e_A e_B\left[w_{11}^A-w_{10}^A\right]-\left(1-e_A\right)e_B\left[w_{01}^A-w_{00}^A\right]-e_A\left(w_{10}^A-w_{00}^A\right)-w_{00}^A\\&-e_B e_A\left[w_{11}^B-w_{10}^B\right]-\left(1-e_B\right)e_A\left[w_{01}^B-w_{00}^B\right]-e_B\left(w_{10}^B-w_{00}^B\right)-w_{00}^B\end{aligned}$$

subject to (8), (9), (10), and (11). Under the optimal contracts, P chooses $[w_{11}^i-w_{10}^i]$, $[w_{01}^i-w_{00}^i]$, and $[w_{10}^i-w_{00}^i]$ to induce optimal incentives and w_{00}^i to extract all rents of the agents ($i=A,B$). Inserting the binding participation constraints

$$e_A\left(1-e_B\right)\alpha_A-\left(1-e_A\right)e_B\beta_A-c_A\left(e_A\right)=$$
$$-e_A e_B\left[w_{11}^A-w_{10}^A\right]-\left(1-e_A\right)e_B\left[w_{01}^A-w_{00}^A\right]-e_A\left(w_{10}^A-w_{00}^A\right)-w_{00}^A$$

and

$$e_B\left(1-e_A\right)\alpha_B-\left(1-e_B\right)e_A\beta_B-c_B\left(e_B\right)=$$
$$-e_B e_A\left[w_{11}^B-w_{10}^B\right]-\left(1-e_B\right)e_A\left[w_{01}^B-w_{00}^B\right]-e_B\left[w_{10}^B-w_{00}^B\right]-w_{00}^B$$

into (12) yields (5), that is, P's objective function under the contracts (w_1^i, w_0^i).

Part B: Validity of the Informativeness Principle in Case of Wealth-Constrained Agents and Positive Rents

If P offers contracts $(w^i_{11}, w^i_{10}, w^i_{01}, w^i_{00})$ $(i = A, B)$ and the participation constraints are non-binding, he will maximize (12) subject to the agents' incentive constraints (8) and (9), which can be rewritten as

$$e_B w^A_{11} + e_B (\beta_A - \alpha_A) + (1 - e_B) w^A_{10} - (1 - e_B) w^A_{00} - e_B w^A_{01} + \alpha_A = c'_A (e_A)$$

and

$$e_A w^B_{11} + e_A (\beta_B - \alpha_B) + (1 - e_A) w^B_{10} - (1 - e_A) w^B_{00} - e_A w^B_{01} + \alpha_B = c'_B (e_B) .$$

Obviously, $w^A_{00} = w^A_{01} = w^B_{00} = w^B_{01} = 0$ are optimal to maximize incentives and reduce implementation costs. Thus, the incentive constraints simplify to

$$e_B w^A_{11} + (1 - e_B) w^A_{10} = c'_A (e_A) - e_B (\beta_A - \alpha_A) - \alpha_A$$

and

$$e_A w^B_{11} + (1 - e_A) w^B_{10} = c'_B (e_B) - e_A (\beta_B - \alpha_B) - \alpha_B.$$

Inserting – together with $w^A_{00} = w^A_{01} = w^B_{00} = w^B_{01} = 0$ – into P's objective function leads to (6), P's objective function under the contracts (w^i_1, w^i_0).

Part C: Second-Order Condition for the Sequential-Move Case:

P maximizes expected profits $\Pi (e_A, e_B (0) , e_B (R))$ being described by (7). As second-order condition, the Hessian matrix

$$\begin{bmatrix} \frac{\partial^2 \Pi}{\partial e_A^2} & \frac{\partial^2 \Pi}{\partial e_A \partial e_B(0)} & \frac{\partial^2 \Pi}{\partial e_A \partial e_B(R)} \\ \frac{\partial^2 \Pi}{\partial e_B(0) \partial e_A} & \frac{\partial^2 \Pi}{\partial e_B^2(0)} & \frac{\partial^2 \Pi}{\partial e_B(0) \partial e_B(R)} \\ \frac{\partial^2 \Pi}{\partial e_B(R) \partial e_A} & \frac{\partial^2 \Pi}{\partial e_B(R) \partial e_B(0)} & \frac{\partial^2 \Pi}{\partial e_B^2(R)} \end{bmatrix} =$$

$$\begin{bmatrix} -c_A''(e_A) & -R+\beta_A-\alpha_B+c_B'(e_B(0)) & R+\beta_B-\alpha_A-c_B'(e_B(R)) \\ -R+\beta_A-\alpha_B+c_B'(e_B(0)) & -(1-e_A)\,c_B''(e_B(0)) & 0 \\ R+\beta_B-\alpha_A-c_B'(e_B(R)) & 0 & -e_A c_B''(e_B(R)) \end{bmatrix}$$

has to be negative definite. This will be the case, if the first principal minor is negative (which is true: $-c_A''(e_A) < 0$), the second principal minor is positive, i.e.,

$$\begin{vmatrix} -c_A''(e_A) & -R+\beta_A-\alpha_B+c_B'(e_B(0)) \\ -R+\beta_A-\alpha_B+c_B'(e_B(0)) & -(1-e_A)\,c_B''(e_B(0)) \end{vmatrix}$$
$$= c_A''(e_A)\,(1-e_A)\,c_B''(e_B(0)) - \left[-R+\beta_A-\alpha_B+c_B'(e_B(0))\right]^2 > 0,$$

which is true since $-R+\beta_A-\alpha_B+c_B'(e_B(0)) = 0$ must hold as first-order condition, and the third principal minor is negative, i.e.,

$$\begin{vmatrix} -c_A''(e_A) & -R+\beta_A-\alpha_B+c_B'(e_B(0)) & R+\beta_B-\alpha_A-c_B'(e_B(R)) \\ -R+\beta_A-\alpha_B+c_B'(e_B(0)) & -(1-e_A)\,c_B''(e_B(0)) & 0 \\ R+\beta_B-\alpha_A-c_B'(e_B(R)) & 0 & -e_A c_B''(e_B(R)) \end{vmatrix}$$

$$= -c_A''(e_A)\begin{vmatrix} -(1-e_A)\,c_B''(e_B(0)) & 0 \\ 0 & -e_A c_B''(e_B(R)) \end{vmatrix}$$
$$-\left(-R+\beta_A-\alpha_B+c_B'(e_B(0))\right)\begin{vmatrix} -R+\beta_A-\alpha_B+c_B'(e_B(0)) & 0 \\ R+\beta_B-\alpha_A-c_B'(e_B(R)) & -e_A c_B''(e_B(R)) \end{vmatrix}$$
$$+\left(R+\beta_B-\alpha_A-c_B'(e_B(R))\right)\begin{vmatrix} -R+\beta_A-\alpha_B+c_B'(e_B(0)) & -(1-e_A)\,c_B''(e_B(0)) \\ R+\beta_B-\alpha_A-c_B'(e_B(R)) & 0 \end{vmatrix}$$

$$
\begin{aligned}
&= -c_A''(e_A)\,(1-e_A)\,c_B''(e_B(0))\,e_A c_B''(e_B(R)) \\
&+ (-R+\beta_A-\alpha_B+c_B'(e_B(0)))^2\,e_A c_B''(e_B(R)) \\
&+ (R+\beta_B-\alpha_A-c_B'(e_B(R)))^2\,(1-e_A)\,c_B''(e_B(0)) < 0,
\end{aligned}
$$

which is true, because we have $-R+\beta_A-\alpha_B+c_B'(e_B(0)) = 0$ and $R+\beta_B-\alpha_A-c_B'(e_B(R)) = 0$ as first-order conditions.