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Pooling Hawks and Doves: Interim-Efficient Labor Contracts for Other-Regarding Agents

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Abstract

This study considers a principal-multiple agents model in which agents are privately informed about their intrinsic motivations to collaborate or to compete. It is shown that the interim-efficient labor contract Pareto-improves *ex interim* upon allocations that are efficient *ex post*. Thus principal and agents can benefit (in expectations) from the composition of social types at work being random. Interim-efficient allocations can be implemented with a screening contract only if the principal can commit herself to hold up her contractual offer regardless of the agents' choices. With imperfect commitment, she can approximate an interim-efficient allocation arbitrarily closely by offering a pooling contract. Interim-efficient pooling implements relative or team performance incentives in a payoff equivalent way. Generally, the distributive effects of interim-efficient contracting are closely related to the hawk-dove game, with workers suffering from less altruistic coworkers. The findings are supported by empirical studies showing that workers' perceived support from coworkers is a key factor for job satisfaction and labor turnover. They indicate that 'corporate culture' has random component associated with coworkers' intrinsic motivations to collaborate or to compete.

Keywords: behavioral contract theory; altruism; spite; asymmetric information; relative and team performance pay; corporate culture

JEL Classification: D64; D82; D86; M50

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1 Introduction

In (behavioral) contract theory it is typically argued that agents who differ in their intrinsic motivations to collaborate or to compete would be screened by principals (e.g. Lazear 1989, Kandel and Lazear 1994), or self-sort in labor market equilibrium (e.g., Frank 1984, Fershtman et al. 2006, Kosfeld and von Siemens 2009, 2011). This view contrasts with the empirical observation that workers' perceived support from coworkers is a key factor for job satisfaction and even labor turnover (e.g., Price and Mueller 1981, Mueller and Price 1990, Riordan and Griffith 1995, Hodson 1997, Ducharme and Martin 2000, Mitchell et al. 2001, Morrison 2004, and Mossholder et al. 2005). That workers have been found to perceive their workplaces as unpleasant if their coworkers' cooperation is poor and might, in response, even change affiliations may have two reasons. One might refer to this observation simply as the outcome of some "trial and error"-matching process, heading towards equilibrium. Or one asks whether the *private* information that workers have on their intrinsic motivations to collaborate or to compete *before* entering on a job may play an economic role in its own right, possibly involving employers and employees in a special form of risk-taking.

This study seeks to shed light on how efficient contracting is impacted by the asymmetry of information on agents' intrinsic motivations to collaborate or to compete. In a principal-two agents model with substitutable efforts and equally productive agents, each agent is privately informed about his more or less pronounced altruistic or spiteful preference toward his coworker. Agents' social types are independent draws from the same, commonly known distribution. Assumptions on the type distribution are fairly weak: its variance is assumed positive, its support is taken arbitrary within a wide range. I endogenously derive labor contracts that are Pareto efficient *ex interim*; that is, at the stage at which each agent has privately learned his type while the principal sticks with her *ex ante* belief about the composition of social types. I show that, in Bayesian equilibrium and from the *ex interim* perspective, the interim-efficient labor contract Pareto dominates any allocation that could be implemented if all parties were fully informed. In particular, the principal is able to exploit the asymmetry of information in order to extract a higher *ex ante* expected profit from the agents' joint product than she could under complete information. *Ex post*, after agents have revealed their types through the actions they have taken, at least one party will be worse off than expected at the interim stage. Interim-efficient contracting thus involves principal and agents in a form of risk-taking with regard to the composition of social types at work. To this extent, it entails the potential for disappointment, or *dissatisfaction* on the job.

Interim Pareto improvement upon allocations that would be Pareto efficient if information

was complete is shown to be feasible for two reasons: First, altruistic (spiteful) preferences allow for substitution of pecuniary with non-pecuniary compensation. And second, at the interim stage, the principal on the one hand and the agents on the other have asymmetric, though rational beliefs about the composition of social types at work: While every privately informed agent has to form a belief about one agent's type only, the principal has to form a belief about the composition of two types. As will be illustrated below, the interplay of these conditions allows for mutually beneficial 'trade' of non-pecuniary compensation. The distributive effects of interim-efficient contracting are closely related to the hawk-dove game, with workers suffering from less altruistic coworkers.

Theoretically, this insight is closely related to Myerson and Satterthwaite (1983). They show that, while trade may not be individually rational if a seller and a buyer are privately informed about their valuations of some good at stake, expected benefits from trade can be realized when introducing a "broker" who can realize a positive *ex ante* expected profit by either subsidizing or exploiting seller and buyer, depending on the realizations of types. In this study, the principal plays the role of a broker who enables privately informed, other-regarding agents to 'trade' non-pecuniary compensation. She charges the agents for providing them with the platform for such social interaction, and the agents are willing to pay.

The analysis distinguishes between interim-efficient *screening* and interim-efficient *pooling*. I show that the interim-efficient allocation can be implemented with a screening contract *only if* the principal is able to commit herself to hold up her contractual offer *after* the agents have revealed their social types and *before* production takes place. The reason is that, under interim-efficient contracting, each party, and so the principal, is *ex interim* willing to take the risk of ending up worse off than in the *ex post* efficient allocation. If the principal cannot commit herself to hold up her contractual offer after having learned the agents' types, then, from the interim perspective, this leads inevitably to a welfare loss. The social costs associated with the principal's imperfect commitment reestablish a 'ratchet effect' (Laffont and Tirole 1988) in the range of asymmetric information on agents' intrinsic motivations to collaborate or to compete. However, the principal can approximate the interim-efficient allocation arbitrarily closely by offering a pooling contract, thereby rendering communication before contracting irrelevant. Offering a pooling contract then serves as a commitment device for the principal. Interim-efficient pooling is shown to implement relative or team performance pay in a payoff equivalent way.¹ Under both compensation schemes, agents are incentivized to reveal their social types through the efforts they exert. That is, truthful revelation of types happens not before but *while* agents engage in production.

¹The term *relative (team) performance pay* is used in this study to mean that each agent's effort imposes a *negative (positive)* externality on his coworker's pay.

Among economists, it is by now widely accepted that many people, in one way or another, internalize the externalities that their actions impose on others. This study restricts attention to the concepts of altruism and spite, which have been shown to be consistent with many people’s behavior in experiments on games of cooperation and competition.² Altruism and spite capture in a straight forward manner the extent to which a worker internalizes the positive or negative externalities that his actions might impose on his coworkers and, thus, his willingness to collaborate or to compete. Neugebauer et al. (2008) explore experimentally the kind of social preferences that people exhibit in the hawk-dove game. They find that, as most participants act selfishly while some act altruistically, behavior is largely consistent with the concept of altruism (and spite). As the interim-efficient labor contract derived from altruistic (spiteful) preferences effectively implements the hawk-dove game between agents (in terms of pecuniary returns), Neugebauer et al. (2008) tell us that, under such incentives, agents can indeed be expected to exhibit altruistic (or spiteful) preferences. In this respect, the model implications are behaviorally consistent with the model assumptions.

The here derived payoff equivalence of relative and team performance pay suggests compromise to the pervasive literature on whether relative performance incentives are superior to team incentives, or vice versa.³ While most studies addressing this question argue in favor of either relative or team performance incentives, in nearly any real-world workplace both kinds of incentives are provided in parallel. This involves consultancies just as political parties and academia.⁴ The here derived payoff equivalence suggests a simple solution to this puzzle. There are few studies that provide explanations to the pervasive coexistence of relative and team incentives. Dur and Sol (2010) rationalize a payoff equivalence of relative and team performance pay by arguing that both kinds of compensation incentivize coworkers to invest in mutual favors, unrelated to production, that are reciprocated with altruism. This altruism helps coworkers to achieve their social optimum. Since coworkers also gain utility from favors, the principal can extract rents by reducing salaries. Fleckinger (2012) shows that, depending on the correlation in coworkers’ products, optimal incentives may involve a combination of relative and team incentives.

While previous studies of determinants of different corporate cultures take a rather static view on the matter⁵, this study suggests that corporate culture is exposed to two sorts

²For evidence on altruism see, e.g., Levine (1998) and Andreoni and Miller (2002). For evidence on spite see, e.g., Saijo and Nakamura (1995), Levine (1998), Herrmann and Orzen (2008), and Prediger et al. (2014). See Carpenter and Seki (2011) for the important finding that participants’ prosocial behavior exhibited in the laboratory is positively correlated with prosocial behavior in a real-world labor environment.

³Fleckinger and Roux (2012) provide an extensive survey on the matter.

⁴Carmichael (1983, p.52) noticed: “If conditions are such that one form is dominant, surely it should be used to the exclusion of others. We observe, on the other hand, many schemes being used at the same time.”

⁵These studies provide rationales for different corporate cultures based on coordination (Kreps 1990),

of dynamics: first, with regard to the social environment at work, corporate culture has a random component associated with workers' intrinsic motivations to collaborate or to compete, potentially leading to dissatisfaction on the job and, if search costs are sufficiently small, perhaps even voluntary turnover; and second, with regard to the sort of labor contracts deployed (individual, relative, or team performance pay), corporate culture has a random component associated with an interchangeability of incentive devices entailing either positive or negative externalities of one agent's effort on another agent's pay. - It is understood that both of these characteristics are unlikely to be found in long-lived workgroups.

The paper proceeds as follows. Section 2 illustrates the economic relevance of asymmetric information on people's social preferences with the help of a simple redistribution game. This example clarifies how a principal can exploit the asymmetry of information on the agents' social types based on the interplay of two conditions inherent to the environment: the substitutability of pecuniary with non-pecuniary compensation, and the asymmetry of rational beliefs about the composition of social types at play. Section 3 outlines the analytical framework and isolates the conditions under which a principal can screen or needs to pool social types in order to exploit the asymmetry of information. It is explained how these conditions relate to the validity of the revelation principle. Sections 4 and 5, respectively, derive interim-efficient screening and pooling contracts. Section 6 illustrates two specific interim-efficient pooling contracts, one implementing relative, the other one team performance pay. Section 7 concludes.

2 A Numerical Example

The following example shows how a principal can exploit asymmetric information on agents' social preferences in order to extract (in expectation) a rent from the agents' material wealth. The principal can design a strategic game between the agents in such a way that (i) each set of the agents' actions determines how wealth is *redistributed* between principal and agents, (ii) each privately informed agent participates *voluntarily* in the game, and (iii) the principal has a *positive ex ante expected profit* from play. As shown below, in the environment under consideration, such a mechanism is not feasible if the agents' social types were commonly known. Hence, the mechanism deployed by the principal must allow for *interim* Pareto improvement upon an allocation that would be Pareto efficient under complete information.

Consider two agents who are each endowed with one monetary unit. A risk neutral

knowledge (Cremer 1993), asymmetric equilibria in product markets (Hermalin 1994), shared beliefs (van den Steen 2010), and separation of different social types in labor market equilibrium (Kosfeld and von Siemens 2009, 2010).

		π_{-i}	
		A	S
π_i	A	$a \setminus a$	$b \setminus c$
	S	$c \setminus b$	$d \setminus d$

Figure 1: The material returns from the strategic game that the principal invites the agents to play. The game is intended to incentivize truthful revelation of types by providing different social types with mutually exclusive dominant strategies: A for an altruist, S for a spiteful type.

principal, P , plans to extract a rent from the agents' wealth. The following is common knowledge among principal and agents. Every agent i exhibits a preference regarding the distribution of material wealth between himself and the other agent. He maximizes utility $u_i = \pi_i + \delta_i \pi_{-i}$, where π_i is i 's wealth, π_{-i} is the other agent's wealth, and δ_i determines i 's social type. Assume for simplicity that agent i is either spiteful, with $\delta_i = -1/2$, or altruistic, with $\delta_i = 1/2$. Agent i 's social type is his private information. Types are *iid* across agents and every agent is equally likely spiteful or altruistic. (Proposition 9 in Section 4 shows how the finding extends to continuous type distributions.) The principal herself seeks material wealth only, and no agent cares about her. We can think of her as (the representative of) a large, faceless organization.

The principal invites the agents to play a redistribution game as follows. Agents i and $-i$ play a strategic game the monetary returns from which are depicted in Figure 1. The game is supposed to incentivize agents to truthfully reveal their types through the actions that they take. Without loss of generality, an *altruist* ($\delta_i = \frac{1}{2}$) is supposed to have the dominant strategy A and a *spiteful* type ($\delta_i = -\frac{1}{2}$) to have the dominant strategy S . The principal is not involved strategically, she rather serves as a 'bank': If both agents are altruistic (spiteful), P transfers $a \in \mathbb{R}$ ($d \in \mathbb{R}$) to each of them and realizes herself a profit of $-2a$ ($-2d$). If one agent is altruistic and the other one spiteful, the altruist receives $b \in \mathbb{R}$, the spiteful type receives $c \in \mathbb{R}$, and P makes a profit of $-b - c$. Assuming that no agent can expend more than his endowment of one, $a, b, c, d \geq -1$ is required. The principal, on the other hand, is assumed to face no capacity constraints whatsoever. The game will be played if and only if

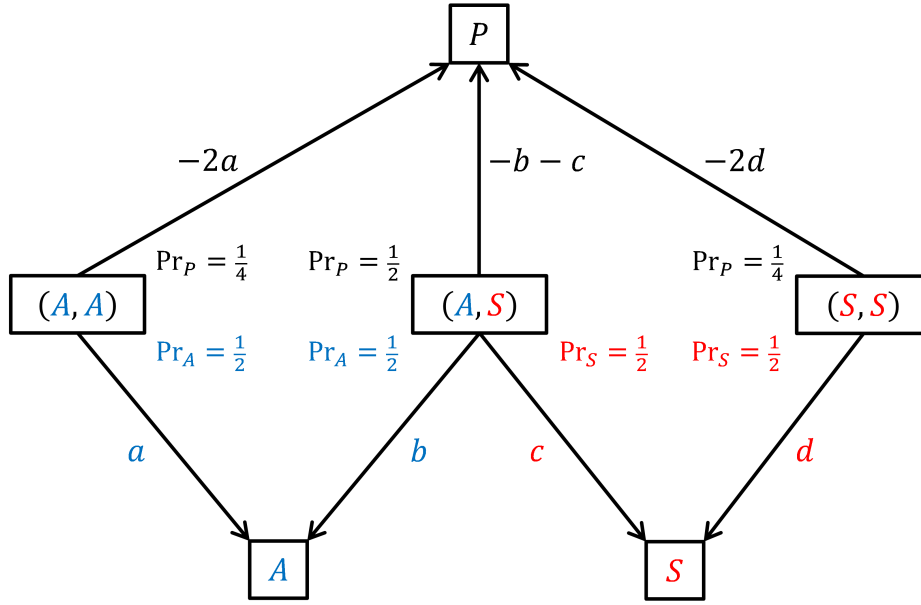


Figure 2: *The monetary returns that the principal (P), an altruist (A), and a spiteful type (S) each would obtain ex post from the feasible compositions of types (\cdot, \cdot) , and the likelihoods (Pr) that principal and agents rationally attribute to each of these compositions to occur.*

each agent agrees upon playing it; otherwise, the game is not played and endowments remain untouched.

That is, the mechanism outlined is required to implement a Perfect Bayesian equilibrium that *interim* Pareto dominates the status quo allocation of one monetary unit for each agent and zero units for P . Notice that, if all parties were fully informed, any redistribution of wealth *guaranteeing* P a positive rent would not find unanimous approval among agents.⁶

Figure 2 depicts the agents' and the principal's beliefs about the different compositions of types to occur as well as the material payoffs they each would obtain respectively. With mutually exclusive dominant strategies for different social types, the agents' types can be identified with their dominant strategies A or S . The principal's *ex ante* belief about possible game outcomes is the binomial distribution $B(2; 1/2)$: Given that types are *iid* and equally likely across agents, she expects each of the compositions (A, A) , (A, S) , (S, A) , and (S, S) to occur with likelihood $\frac{1}{4}$. By symmetry, she will be equally affected by compositions (A, S) and (S, A) , so she attributes likelihood $\frac{1}{2}$ to meeting one hawk and one dove. On the other hand, each privately informed agent has the updated, or *interim* belief $B(1; 1/2)$: For an altruist

⁶This results from Lemma 1 in Section 4. The reason is essentially that each type values a unit of own wealth more than an increase (or decrease) of his opponent's wealth by the same amount, since $|\delta_i| < 1$.

(A) it is equally likely to meet another A or a spiteful type (S). He attributes likelihood zero to composition (S, S). Similarly, it is equally likely for an A to meet an S or another A , and he attributes likelihood zero to composition (A, A). Rational beliefs about the composition of types at play are thus asymmetric between the principal on the one hand and the agents on the other. Obviously, P 's *ex ante* expected profit equals $-(a + b + c + d)/2$.

Denote by $u_i(s_i, s_{-i} | \delta_i) = \pi_i(s_i, s_{-i}) + \delta_i \pi_{-i}(s_{-i}, s_i)$ the utility that an agent i of type δ_i gains from play if he chooses the strategy s_i and his opponent chooses the strategy s_{-i} , with $s_i, s_{-i} \in \{A, S\}$. Denote by $\mathbb{E}_{\delta_{-i}}[u_i | \delta_i] = \mathbb{E}_{\delta_{-i}}[u_i(s_i(\delta_i), s_{-i}(\delta_{-i}) | \delta_i)]$ the *interim* expected utility that agent i of type δ_i gains from play, with type-contingent dominant strategies $s_i(\delta_i), s_{-i}(\delta_{-i})$. Then the principal's optimization problem takes the form

$$\max_{a,b,c,d \geq -1} -(a + b + c + d)/2 \quad (1)$$

subject to the following constraints:

$$\begin{aligned} A1 & : & 0 < u_i(A, A | 1/2) - u_i(S, A | 1/2) &= (a + a/2) - (c + b/2), \\ A2 & : & 0 < u_i(A, S | 1/2) - u_i(S, S | 1/2) &= (b + c/2) - (d + d/2), \\ A3 & : & 0 \leq \mathbb{E}_{\delta_{-i}}[u_i | 1/2] &= (a + a/2)/2 + (b + c/2)/2, \\ S1 & : & 0 < u_i(S, A | -1/2) - u_i(A, A | -1/2) &= (c - b/2) - (a - a/2), \\ S2 & : & 0 < u_i(S, S | -1/2) - u_i(A, S | -1/2) &= (d - d/2) - (b - c/2), \\ S3 & : & 0 \leq \mathbb{E}_{\delta_{-i}}[u_i | -1/2] &= (c - b/2)/2 + (d - d/2)/2. \end{aligned}$$

The incentive compatibility constraints $A1$ and $A2$ ($S1$ and $S2$) ensure that an altruist (a spiteful type) has the dominant strategy A (S). Comparison with Figure 2 shows that constraint $A3$ ($S3$) ensures an altruist's (a spiteful type's) participation in the game, provided that altruists play A and spiteful types play S : his *interim* expected utility from play must exceed his utility from non-play, which equals $0 + 0/2$ ($0 - 0/2$). Due to the linearity of utility functions, the agents' endowments can be neglected when stating the above incentive compatibility and participation constraints. If $A1$ to $S3$ are jointly satisfied, unanimous agreement to play is the outcome of a Perfect Bayesian equilibrium, and in this equilibrium agreeing to play is a weakly dominant strategy for each type.

The simplex algorithm informs us that the linear program (1) has the unique solution $(a^*, b^*, c^*, d^*) = (2/3, -1, 0, -1)$, which yields P an *ex ante* expected profit of $2/3$ in the Perfect Bayesian equilibrium with unanimous agreement to play. Hence, P is indeed able to exploit the asymmetry of information on the agents' social types in order to provide herself with a positive expected rent out of the agents' pockets. In particular, the derived

mechanism *interim* Pareto dominates the status quo allocation, even though that allocation would be Pareto efficient if all parties were fully informed. In the remainder of this section, this finding is to be outlined in more detail and to be interpreted.

Plugging the optimal solution into the constraints of (1) shows that types have indeed mutually exclusive strictly dominant strategies. The participation constraints, $A3$ and $S3$, are both binding, such that types are just indifferent between rejecting and agreeing to play.⁷ An altruist's expected utility from play, provided participation of the other agent $-i$, can be written as

$$\mathbb{E}_{\delta_{-i}} [u_i | \delta_i] = \mathbb{E}_{\delta_{-i}} [\pi_i | \delta_i] + \delta_i \mathbb{E}_{\delta_{-i}} [\pi_{-i} | \delta_i] = (a^* + b^*)/2 + \delta_i (a^* + c^*)/2, \quad (2)$$

with $\mathbb{E}_{\delta_{-i}} [\pi_i | \delta_i]$ denoting the agent's expected own wealth from play, and with $\mathbb{E}_{\delta_{-i}} [\pi_{-i} | \delta_i]$ denoting his expected externality on his opponents' wealth. The term $\delta_i \mathbb{E}_{\delta_{-i}} [\pi_{-i} | \delta_i]$ can be interpreted as agent i 's (expected) *mental compensation*. In particular, agent i is willing to substitute material compensation with mental compensation. With $(a^*, b^*, c^*) = (2/3, -1, 0)$ and $\delta_i = 1/2$, the altruist's mental compensation exactly balances his material loss: $\delta_i \mathbb{E}_{\delta_{-i}} [\pi_{-i} | \delta_i] = 1/6$ and $\mathbb{E}_{\delta_{-i}} [\pi_i | \delta_i] = -1/6$. Similarly, a spiteful type's expected utility from play, provided participation of the other agent $-i$, can be written as

$$\mathbb{E}_{\delta_{-i}} [u_i | \delta_i] = \mathbb{E}_{\delta_{-i}} [\pi_i | \delta_i] + \delta_i \mathbb{E}_{\delta_{-i}} [\pi_{-i} | \delta_i] = (d^* + c^*)/2 + \delta_i (d^* + b^*)/2. \quad (3)$$

With $(b^*, c^*, d^*) = (-1, 0, -1)$ and $\delta_i = -1/2$, also the spiteful type's mental compensation exactly balances his material loss: $\delta_i \mathbb{E}_{\delta_{-i}} [\pi_{-i} | \delta_i] = 1/2$ and $\mathbb{E}_{\delta_{-i}} [\pi_i | \delta_i] = -1/2$.

When plugging (a^*, b^*, c^*, d^*) into Figure 2, it becomes clear how the different compositions of types contribute to P 's rent. The composition (S, S) yields her an ex post profit of $-2d^* = 2$ and occurs with likelihood $1/4$, the mixed composition (A, S) yields her an ex post profit of $-b^* - c^* = 1$ and occurs with likelihood $1/2$. Hence, P 's expected profit from meeting *at least one* spiteful type is 1. Ending up with two altruists, (A, A) , is expensive and yields her a *loss* of $4/3$. However, for P this event only occurs with likelihood $1/4$, such that total expected returns are positive, $2/3$. Notice that, for an altruist, the beneficial event (A, A) is twice as likely as for P , such that it is relatively "cheap" for P to compensate the altruist for his loss in the event (A, S) .

As illustrated by the above example, the ingredients allowing for interim Pareto improvement upon an allocation that would be Pareto efficient if all parties were fully informed are

⁷Notice that P could strengthen the incentives to play by adding $\varepsilon > 0$ monetary units to each outcome component of the game. For any ε sufficiently small, such "global transfer" would yield strict interim Pareto improvement upon the status quo allocation without distorting incentives.

the substitutability of material with mental compensation and the asymmetry of rational beliefs about the composition of types at play.

3 The Model

A risk-neutral, profit maximizing principal P hires two agents, interchangeably referred to as i and $-i$. Agents are risk-neutral and, physically, equally productive. Their efforts are observable and perfectly substitutable. For his individual effort $x_i \geq 0$, agent i faces costs $C(x_i)$, where $C : [0, \infty) \rightarrow [0, \infty)$ satisfies $C(0) = C_x(0) = 0$, $C_x > 0$ for all $x > 0$, $\lim_{x \rightarrow \infty} C_x(x) = \infty$, and $C_{xx} > 0$.⁸ Total output equals joint effort, $x_i + x_{-i}$, and is sold at an exogenous market price of 1 per unit. Production is incentivized by a pair of labor contracts $[W_i; W_{-i}] = [w_i(x_i, x_{-i}); w_{-i}(x_{-i}, x_i)]$, where $w_i(x_i, x_{-i})$ and $w_{-i}(x_{-i}, x_i)$ denote respectively the wages of agents i and $-i$. Due to limited liability, $w_i(x_i, x_{-i}), w_{-i}(x_{-i}, x_i) \geq 0$ for all $x_i, x_{-i} \geq 0$.

For given efforts, P gains a profit of $\pi_P = x_i + x_{-i} - w_i(x_i, x_{-i}) - w_{-i}(x_{-i}, x_i)$, while agent i realizes a material wealth of $\pi_i = w_i(x_i, x_{-i}) - C(x_i)$. Each agent exhibits a more or less pronounced altruistic or spiteful preference with regard to the distribution of wealth between himself and his coworker. From his own wealth π_i , and a wealth of π_{-i} for $-i$, agent i gains utility

$$U_i = \pi_i + \delta_i \pi_{-i}, \quad (4)$$

where $\delta_i \in [\delta_{\min}, \delta_{\max}] \subset [-1, 1]$, with $\delta_{\min} < \delta_{\max}$. The weight δ_i denotes i 's *degree of altruism* (which might be negative) toward his coworker $-i$, or i 's *social type*. Every agent's type is exogenously given and assumed to be unaffected by his coworker's type. The location of the interval $[\delta_{\min}, \delta_{\max}]$ within $(-1, 1)$ is taken arbitrary, explicitly allowing for 'populations' of agents exclusively containing altruistic ($\delta_{\min} > 0$) or spiteful ($\delta_{\max} < 0$) types.

It is common knowledge among $\{P, i, -i\}$ that the agents' social types are independent draws from the same distribution, given by the c.d.f. $F : [\delta_{\min}, \delta_{\max}] \rightarrow [0, 1]$. F is continuously differentiable, and its density f satisfies $f(\delta_{\min}) = 0 = f(\delta_{\max})$, while $f(\delta) > 0$ at each $\delta \in (\delta_{\min}, \delta_{\max})$.⁹ The following Lemma characterizes efficient contracting under complete information (i.e., under the assumption that, before contracting, each agent's type is observable to every other party.)

⁸Throughout the paper, f_x and f_{xx} denote respectively the first and second derivative of a twice differentiable function $f : \mathbb{R} \rightarrow \mathbb{R}$. For a twice partially differentiable mapping $g : \mathbb{R}^2 \rightarrow \mathbb{R}$, the first and second derivative w.r.t. the first (second) component are denoted by g_1 (g_2) and g_{11} (g_{22}), respectively; cross partial derivatives are not deployed.

⁹Qualitatively, all the results of this study are equally valid for type distributions containing mass points.

Lemma 1 *Under complete information, any efficient labor contract incentivizes each agent, regardless of his social type, to exert the effort $x^* = C_x^{-1}(1)$. For any composition of social types, any distribution of the total returns from production among principal and agents is Pareto efficient. The pair of contracts $[W_i^*; W_{-i}^*] = [x_i; x_{-i}]$ implements the Pareto efficient allocation $[\underline{\pi}_P; \underline{u}(\delta_i); \underline{u}(\delta_{-i})] = [0; (1 + \delta_i)R; (1 + \delta_{-i})R]$, where $R = x^* - C(x^*)$.*

Proof. See Appendix A. ■

Since $|\delta_i| < 1$, each social type's marginal utility from own wealth is greater than his marginal utility (or disutility, if $\delta_i < 0$) from his coworker's wealth. This implies, on the one hand, that there is no redistribution of wealth between $\{P, i, -i\}$ that would find unanimous approval. On the other hand, each type wants the 'cake' that is to be distributed among $\{P, i, -i\}$ (that is, total output net of total effort costs) to be maximal. In the following, the allocation implemented by the pair of contracts $[W_i^*; W_{-i}^*]$ of Lemma 1 is taken to characterize the agents' reservation utilities.

Definition 2 *The allocation $[\underline{\pi}_P; \underline{u}(\delta_i); \underline{u}(\delta_{-i})] = [0; (1 + \delta_i)R; (1 + \delta_{-i})R]$, where $R = x^* - C(x^*)$, determines each type δ_i 's reservation utility $\underline{u}(\delta_i)$ and is referred to as the status quo of efficient contracting under complete information; briefly, the **status quo**.*

In the status quo of efficient contracting under complete information, agents are symmetric in terms of reservation wealth R . Since agents are physically equally productive and efforts are perfectly substitutable, while, by Lemma 1, any distribution of wealth among the agents is Pareto efficient, there is no economic reason to discriminate between different social types. The assumption of zero profits for P is arbitrary and simply states that all bargaining power lies in the hands of the agents. All results hold equally when considering status quo allocations $[\underline{\pi}_P; \underline{u}(\delta_i); \underline{u}(\delta_{-i})] \in \{[2r; (1 + \delta_i)(R - r); (1 + \delta_{-i})(R - r)] \mid r \in [0, R]\}$, each of which is Pareto efficient by Lemma 1.

Suppose in the following that each agent i learns his type privately before contracting with P and $-i$. In order to provide herself with a positive (expected) profit, P seeks to exploit the information asymmetry by offering the agents a menu of contracts that differ from those implementing the status quo of Definition 2. In the respective game, the timing of belief formation and decision making is as follows:

Stage 1: Principal and agents form a common prior about the composition of types at work. According to the assumptions above, $(\delta_i, \delta_{-i}) \sim F \times F$.

Stage 2: Agents i and $-i$ each learn their types privately. Agents update their beliefs about the composition of types at work: i 's updated belief is $\delta_{-i} \sim F$; $-i$'s updated belief

is $\delta_i \sim F$. The principal sticks with her prior $(\delta_i, \delta_{-i}) \sim F \times F$.

Stage 3: The principal offers each agent i the (publicly observable) menu of contracts

$$\mathbb{W} = \{w[m_i, m_{-i}](x_i, x_{-i}) \mid m_i, m_{-i} \in [\delta_{\min}, \delta_{\max}]\}, \quad (5)$$

where m_i, m_{-i} are specified as follows.

Stage 4: Agents i and $-i$ observe the menu \mathbb{W} and decide simultaneously on whether they accept or reject to choose from \mathbb{W} . If at least one agent rejects, the status quo allocation is ultimately implemented with the contracts $[W_i^*; W_{-i}^*]$ from Lemma 1; in this case, the game proceeds with stage 7. If both agents accept, the game proceeds with stage 5.

The requisite of unanimous approval of \mathbb{W} serves the purpose of characterizing the Pareto frontier of allocations that are feasible *ex interim* (i.e, before the asymmetry of information has been resolved).

Stage 5: If both agents accept at stage 4 to choose from \mathbb{W} , then i and $-i$ simultaneously send messages $m_i, m_{-i} \in [\delta_{\min}, \delta_{\max}]$ to P .

Stage 6 (Perfect Commitment): If the principal *can commit* herself to the menu \mathbb{W} offered at stage 3, then, based on the messages m_i, m_{-i} received at stage 5, she utilizes the pair of contracts $[W_i; W_{-i}] = [w[m_i, m_{-i}]; w[m_{-i}, m_i]]$ as specified at stage 3.

Stage 6* (Imperfect Commitment): If, *instead*, the principal *cannot commit* herself to her offer \mathbb{W} from stage 3, then, based on the messages m_i, m_{-i} received at stage 5, she may ultimately implement the status quo with the pair of contracts $[W_i^*; W_{-i}^*]$ from Lemma 1.

Stage 7: Agents i and $-i$ simultaneously choose their efforts x_i, x_{-i} under the pair of labor contracts determined at stages 4 to 6 (or 6*).

Stage 8: Efforts are observed by P , and wage payments are made according to the pair of labor contracts determined at stages 4 to 6 (or 6*).

The game specified by stages 1 to 8 guarantees each social type δ_i his reservation utility $\underline{u}(\delta_i)$. Refer in the following to any menu $\mathbb{W} = \{w[m_i, m_{-i}](x_i, x_{-i}) \mid m_i, m_{-i}\}$ that incentivizes truthful revelation at stage 5 as a *screening contract*. That is, screening is supposed to incentivize truthful revelation *before* production takes place. Conversely, refer to any singleton menu $\mathbb{W} = \{w(x_i, x_{-i})\}$ as a *pooling contract*; in this case, communication at stage 5 is made irrelevant: $w[m_i, m_{-i}](\cdot, \cdot) = w(\cdot, \cdot)$ for any pair of messages sent. Pooling is supposed to incentivize truthful revelation *while* production takes place; that is, agents are incentivized to reveal their social types through the efforts they exert.

As specified at stage 5, communication between principal and agents is *direct*: the agents' message spaces coincide with their (identical) type spaces. If the principal can commit herself

to hold up her contract offers from stage 3 at stage 6, the focus on direct communication is fully in line with the *revelation principle* (e.g., Myerson 1979).¹⁰ However, as shown in Bester and Strausz (2000) and Evans and Reiche (2008), the revelation principle does not generally apply if a principal who faces more than one agent has the option to withdraw her contractual offer *after* having learned the agents' types (that is, more formally speaking, if the principal cannot commit herself to an allocation function.) However, for the purpose of this paper it suffices to restrict attention to direct communication also in the case of imperfect commitment.

In the following, the operators $\mathbb{E}_\delta[\cdot]$ and $\text{Var}_\delta[\cdot]$ are with respect to F . The assumptions on F imply that $\text{Var}_\delta[\delta] > 0$. Denote by $\mathbb{E}_{\delta_{-i}}[g(\delta_i, \delta_{-i})]$ the conditional expected value of a measurable random variable $g(\delta_i, \delta_{-i})$ for a given value of δ_i . The operator $\mathbb{E}_{\delta_i, \delta_{-i}}[\cdot]$ indicates that expectations are taken over the joint distribution $F \times F$ of two independent draws $\delta_i, \delta_{-i} \in [\delta_{\min}, \delta_{\max}]$. Denote by

$$\begin{aligned} U_i[\delta_i; m_i, m_{-i}, x_i, x_{-i}] &= w[m_i, m_{-i}](x_i, x_{-i}) - C(x_i) \\ &\quad + \delta_i[w[m_{-i}, m_i](x_{-i}, x_i) - C(x_{-i})] \end{aligned} \quad (6)$$

agent i 's ex post utility from work under the pair of contracts $W_i = w[m_i, m_{-i}](x_i, x_{-i})$ and $W_{-i} = w[m_{-i}, m_i](x_{-i}, x_i)$ if his true social type is δ_i , while i and $-i$ have sent messages m_i, m_{-i} and have exerted efforts x_i, x_{-i} . Denote by

$$\pi_P[\delta_i, \delta_{-i}; m_i, m_{-i}, x_i, x_{-i}] = x_i - w[m_i, m_{-i}](x_i, x_{-i}) + x_{-i} - w[m_{-i}, m_i](x_{-i}, x_i) \quad (7)$$

the principal's ex post profit from $W_i = w[m_i, m_{-i}](x_i, x_{-i})$ and $W_{-i} = w[m_{-i}, m_i](x_{-i}, x_i)$ if agents of true types δ_i, δ_{-i} have sent messages m_i, m_{-i} and have exerted efforts x_i, x_{-i} .

For the purpose of this paper it suffices to restrict attention to pairs of labor contracts that each provide any social type with a (type-dependent) dominant effort strategy. Denote by $x_i^*(\delta_i; m_i, m_{-i})$ agent i 's dominant effort strategy under the pair of contracts determined by the pair of sent messages (m_i, m_{-i}) provided that i 's true type is δ_i . Then the principal's maximization problem (with perfect or imperfect commitment) takes the following form.

$$\max_{w\cdot, \cdot} \mathbb{E}_{\delta_i, \delta_{-i}} [\pi_P[\delta_i, \delta_{-i}; \delta_i, \delta_{-i}, x_i^*(\delta_i; \delta_i, \delta_{-i}), x_{-i}^*(\delta_{-i}; \delta_{-i}, \delta_i)]] \quad (8)$$

such that the following constraints are jointly satisfied:

$$(I) \text{ (limited liability) } \forall i, \forall m_i, m_{-i} \in [\delta_{\min}, \delta_{\max}], \forall x_i, x_{-i} \geq 0: \quad w[m_i, m_{-i}](x_i, x_{-i}) \geq 0.$$

¹⁰Notice that Myerson's (1979) formulation of the revelation principle particularly applies to agents who exhibit other-regarding preferences.

(II) (*dominant effort strategies at stage 7*) $\forall i, \forall \delta_i, m_i, m_{-i} \in [\delta_{\min}, \delta_{\max}], \forall x_i, x_{-i} \geq 0$:

$$U_i [\delta_i; m_i, m_{-i}, x_i^* (\delta_i; m_i, m_{-i}), x_{-i}] \geq U_i [\delta_i; m_i, m_{-i}, x_i, x_{-i}]. \quad (9)$$

This constraint takes into account that the set of contracts under which each agent i chooses his effort has already been determined by the messages m_i, m_{-i} sent before, at stage 5.

(III) (*truthful revelation in PBE, at stage 5*) $\forall i, \forall \delta_i \in [\delta_{\min}, \delta_{\max}]$:

$$\begin{aligned} & \mathbb{E}_{\delta_{-i}} [U_i [\delta_i; \delta_i, \delta_{-i}, x_i^* (\delta_i; \delta_i, \delta_{-i}), x_{-i}^* (\delta_{-i}; \delta_{-i}, \delta_i)]] \\ & \geq \mathbb{E}_{\delta_{-i}} [U_i [\delta_i; m_i, \delta_{-i}, x_i^* (\delta_i; m_i, \delta_{-i}), x_{-i}^* (\delta_{-i}; \delta_{-i}, m_i)]] . \end{aligned} \quad (10)$$

(IV) (*individual rationality at stage 4*) $\forall i, \forall \delta_i \in [\delta_{\min}, \delta_{\max}]$:

$$\mathbb{E}_{\delta_{-i}} [U_i [\delta_i; \delta_i, \delta_{-i}, x_i^* (\delta_i; \delta_i, \delta_{-i}), x_{-i}^* (\delta_{-i}; \delta_{-i}, \delta_i)]] \geq (1 + \delta_i) R = \underline{u} (\delta_i). \quad (11)$$

This constraint requires that agents' interim expected utilities in the PBE with truthful revelation exceed their status quo utilities. The following constraint determines whether or not P can commit to hold up her contractual offer after having learned the agents' types (at stage 6 or 6*):

(V*) (*imperfect commitment at stage 6*, optional*) $\forall \delta_i, \delta_{-i} \in [\delta_{\min}, \delta_{\max}]$:

$$\pi_P [\delta_i, \delta_{-i}; \delta_i, \delta_{-i}, x_i^* (\delta_i, \delta_{-i}), x_{-i}^* (\delta_{-i}, \delta_i)] \geq 0 = \underline{\pi}_P. \quad (12)$$

Definition 3 A menu of contracts \mathbb{W} (possibly a singleton) is said to **interim Pareto dominate the status quo in Perfect Bayesian equilibrium (PBE)** if and only if it satisfies the constraints (I) to (IV) of the principal's problem (8) and yields the principal a positive ex ante expected profit.

As is immediate from Lemma 1, there exists no screening contract that Pareto dominates the status quo in PBE if the constraint (11) is required to hold for any *realization* of δ_{-i} . Hence, if agents have the option to reject the pair of contracts $[W_i; W_{-i}] = [w [m_i, m_{-i}] (\cdot, \cdot); w [m_{-i}, m_i] (\cdot, \cdot)]$ after having learned each other's type (that is, after stages 6 or 6* and before stage 7), then there exists no screening contract, which incentivizes truthful revelation at stage 5, that finds unanimous approval and yields P a positive ex ante

expected profit.¹¹ In order to analyze the role of P 's perfect or imperfect commitment, it is assumed in the following that the agents do not have the option to reconsider their participation after stage 5.

Notice next that P cannot provide herself with a positive profit without taking the risk of ending up with a loss:

Lemma 4 *Any menu of contracts that satisfies constraints (I) to (IV) of the principal's problem (8) and yields the principal a positive ex ante expected profit necessarily violates constraint (V^*).*

Proof. See Appendix A. ■

By Lemma 4, there exists no menu of contracts that jointly incentivizes truthful revelation of the agents' social types, interim Pareto dominates the status quo in PBE, and guarantees the principal a non-negative profit. That is, for any screening or pooling contract that interim Pareto dominates the status quo in PBE, there must exist combinations of social types for which the principal is ex post not better off than in the status quo. This implies:

Proposition 5 *Suppose the principal cannot commit herself to implement the agents' choices from a menu of contracts. Then there exists no screening contract that interim Pareto dominates the status quo in PBE.*

Proof. Immediate from Lemma 4 and the constraint (V^*) in P 's problem (8). ■

By Proposition 5, imperfect commitment of P implies that any menu of contracts that interim Pareto dominates the status quo in PBE must avoid truthful revelation at stage 5. In particular, the allocation implemented in PBE by the screening contract derived in section 4, Proposition 9, cannot be implemented with truthful revelation at stage 5. As shown in section 5, the principal, when being constrained to imperfect commitment, can implement interim Pareto improvement upon the status quo by offering a pooling contract. Principal-agent communication at stage 5 is then made irrelevant. It is shown that interim-efficient pooling distorts the incentives to exert effort in such a way that the agents reveal their social types through the efforts they exert. That is, the agents' types are observed *ex post*, but *not ex interim*. In light of Proposition 5, interim-efficient pooling can be interpreted as a commitment device for the principal.

¹¹In that case, P could realize a positive ex ante expected profit by offering an interim-efficient *pooling* contract at stage 3 (as characterized in Section 6) and suppressing communication at stage 5.

4 Interim-Efficient Screening

This section characterizes screening contracts that interim Pareto dominate the status quo in PBE. First, necessary conditions are derived. These conditions are then met with sufficient conditions.

Suppose the principal can commit herself to implement the agents' contract choices after having learned the agents' types (at stage 6). As suggested by Lemma 1, the principal then offers a screening contract that enforces efficient production for any composition of social types:

Lemma 6 *Any interim-efficient screening contract $\mathbb{W} = \{w[m_i, m_{-i}](x_i, x_{-i}) \mid m_i, m_{-i}\}$ incentivizes each agent, regardless of his type, to exert the effort $x^* = C_x^{-1}(1)$.*

Proof. The proof closely follows the lines of the proof of Lemma 1, part (i), in Appendix A and is omitted therefore. ■

By Lemma 6, agents must be incentivized to exert the efficient effort level x^* , implying that agents, regardless of their types, face the same costs of effort. The agents' contract choices then only affect their wage payments. Abstract for the moment, until Proposition 9, from the limited liability constraint (I) in P 's problem (8). Then an interim-efficient screening contract that incentivizes efficient production while satisfying the constraints (II) to (IV) can, without loss of generality, be written as

$$\mathbb{W}^s = \{v(m_i, m_{-i}) + x_i \mid m_i, m_{-i} \in [\delta_{\min}, \delta_{\max}]\}, \quad (13)$$

where the salary component $v : [\delta_{\min}, \delta_{\max}]^2 \rightarrow \mathbb{R}$ incentivizes truthful revelation. A type δ_i 's expected utility from implementation of \mathbb{W}^s then satisfies

$$\begin{aligned} \mathbb{E}_{\delta_{-i}} [U_i[\delta_i; \delta_i, \delta_{-i}, x^*, x^*]] &= \mathbb{E}_{\delta_{-i}} [v(\delta_i, \delta_{-i}) + R] + \delta_i \mathbb{E}_{\delta_{-i}} [v(\delta_{-i}, \delta_i) + R] \\ &= (1 + \delta_i) R + \mathbb{E}_{\delta_{-i}} [v(\delta_i, \delta_{-i})] + \delta_i \mathbb{E}_{\delta_{-i}} [v(\delta_{-i}, \delta_i)] \\ &= (1 + \delta_i) R + u(\delta_i) \end{aligned} \quad (14)$$

for some real number $u(\delta_i) \geq 0$. The mapping

$$u : \begin{cases} [\delta_{\min}, \delta_{\max}] \rightarrow [0, \infty) \\ \delta_i \mapsto u(\delta_i) \end{cases} \quad (15)$$

determines each type δ_i 's interim expected utility gain from implementation of \mathbb{W}^s . Accordingly, u is referred to as the *gain function*.

The following Lemma suggests a procedure for the derivation of interim-efficient screening contracts. It states that, in any PBE that interim Pareto dominates the status quo, the gain function must satisfy certain conditions and that, for any valid gain function, the expected distributive effects of any screening contract that implements the PBE in question are then fully determined by that gain function. Based on these necessary conditions, interim-efficient screening contracts can be derived by, first, identifying a valid gain function u and, second, determining labor contracts that implement u in PBE.

Lemma 7 *Suppose there is a screening contract $\mathbb{W}^s = \{v(m_i, m_{-i}) + x_i \mid m_i, m_{-i}\}$, with $v : [\delta_{\min}, \delta_{\max}]^2 \rightarrow [0, \infty)$ twice partially continuously differentiable, that interim Pareto dominates the status quo in PBE and implements interim expected utilities $\mathbb{E}_{\delta_{-i}} [U_i[\delta_i; \delta_i, \delta_{-i}, x^*, x^*]] = (1 + \delta_i)R + u(\delta_i)$, with $u(\delta_i) \geq 0$ at each δ_i . Then the following holds necessarily:*

- (i) *The gain function $u : [\delta_{\min}, \delta_{\max}] \rightarrow [0, \infty)$ is twice differentiable and strictly convex. It satisfies $\mathbb{E}_{\delta} [u_{\delta}(\delta)] < 0$ and $\mathbb{E}_{\delta} [u(\delta)] = \mathbb{E}_{\delta} [(1 + \delta)u_{\delta}(\delta)]$.*
- (ii) *The principal has an ex ante expected profit of $\mathbb{E}_{\delta_i, \delta_{-i}} [\pi_P] = 2 |\mathbb{E}_{\delta} [u_{\delta}(\delta)]|$.*
- (iii) *Type δ_i has an interim expected wealth of $\mathbb{E}_{\delta_{-i}} [\pi_i | \delta_i] = R + u(\delta_i) - \delta_i u_{\delta}(\delta_i)$.*
- (iv) *Type δ_i expects ex interim a wealth of $\mathbb{E}_{\delta_{-i}} [\pi_{-i} | \delta_i] = R + u_{\delta}(\delta_i)$ for coworker $-i$.*

Proof. See Appendix A. ■

The gain function fully determines an agent's own expected wealth, $\mathbb{E}_{\delta_{-i}} [\pi_i | \delta_i]$, as well as the expected externality he imposes on his coworker's wealth, $\mathbb{E}_{\delta_{-i}} [\pi_{-i} | \delta_i]$. A stylized illustration of these conditional expectations as functions of an agent's type is given in Figure 3. Own expected wealth is inverse U-shaped, since $d\mathbb{E}_{\delta_{-i}} [\pi_i | \delta_i] / d\delta_i = -\delta_i u_{\delta\delta}(\delta_i)$, and $u_{\delta\delta} > 0$. It is largest for the pure payoff maximizer, $\delta_i = 0$; his own expected wealth must not be smaller than in the status quo for he does not internalize the externality he imposes on others. The more an agent internalizes the externality he imposes on his coworker (i.e., the larger $|\delta_i|$), the more rent can P extract by substituting material compensation, $\mathbb{E}_{\delta_{-i}} [\pi_i | \delta_i]$, with mental compensation, $\delta_i \mathbb{E}_{\delta_{-i}} [\pi_{-i} | \delta_i]$.

As $u_{\delta\delta} > 0$ by Lemma 7(iv), an agent i 's expected externality on his coworker's wealth strictly increases in i 's social type, . As compared to the status quo, the least altruistic type imposes a negative externality on his coworker's wealth, $u_{\delta}(\delta_{\min}) < 0$.¹² The most altruistic type imposes a positive externality on his coworker's wealth, $u_{\delta}(\delta_{\max}) > 0$.¹³

¹²This is immediate from $\mathbb{E}_{\delta} [u_{\delta}(\delta)] < 0 < u_{\delta\delta}$.

¹³Suppose the opposite: $u_{\delta}(\delta_{\max}) \leq 0$. Then $u_{\delta} \leq 0$, since $u_{\delta\delta} > 0$. Hence, $\mathbb{E} [(1 + \delta)u_{\delta}(\delta)] \leq 0$, since $0 < 1 + \delta$ for all $\delta \in [\delta_{\min}, \delta_{\max}]$. However, by Lemma 7(i), $0 < \mathbb{E} [u(\delta)] = \mathbb{E} [(1 + \delta)u_{\delta}(\delta)] \leq 0$; a contradiction.

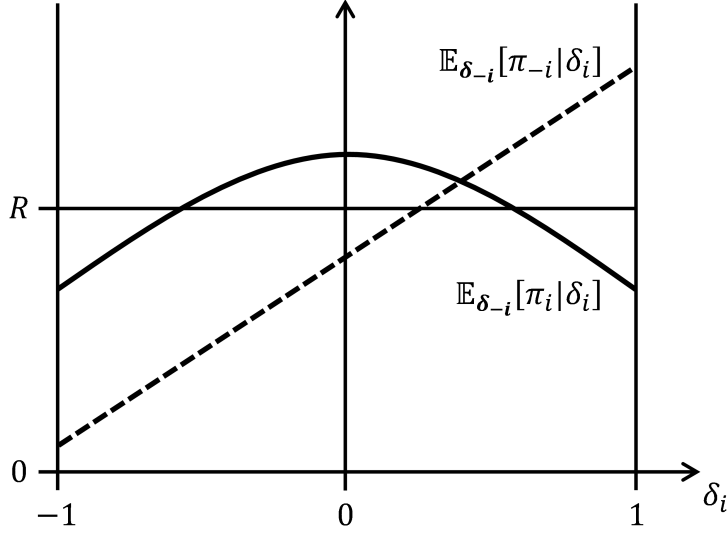


Figure 3: A stylized illustration of an agent's expectations about his own wealth, $\mathbb{E}_{\delta_i}[\pi_i | \delta_i]$, and his coworker's wealth, $\mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i]$, both as functions of the agent's type δ_i .

Aggregate expected individual wealth amounts to $\mathbb{E}_{\delta_i, \delta_{-i}}[\pi_{-i}] = R - |\mathbb{E}_{\delta}[u_{\delta}(\delta)]|$.¹⁴ The term $|\mathbb{E}_{\delta}[u_{\delta}(\delta)]| > 0$ determines (half of) P 's expected profit and measures the extent of (aggregate expected) redistribution from the agents to the principal. For this material loss, as compared to the status quo, the agents receive mental compensation of $\mathbb{E}_{\delta_i}[\delta_i \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i]] = \mathbb{E}_{\delta}[\delta]R + \mathbb{E}_{\delta}[\delta u_{\delta}(\delta)]$. By Lemma 7(i), P 's share in mental compensation amounts to $|\mathbb{E}_{\delta}[u_{\delta}(\delta)]| = \mathbb{E}_{\delta}[\delta u_{\delta}(\delta)] - \mathbb{E}_{\delta}[u(\delta)]$, where $\mathbb{E}_{\delta}[u(\delta)] > 0$ is the agents' aggregate expected utility gain.

The conditions of Lemma 7(i) are invariant under a multiplication of u with a positive scalar. This property is important when it comes to the agents' limited liability. As suggested by Lemma 7(iii,iv), the magnitudes of u and u_{δ} do impact the agents' ex post wage payments. Limited liability requires that the gain function u , and thus the extent of aggregate redistribution between the principal and the agents, has a sufficiently small upper bound. The next Lemma shows that a gain function as required by Lemma 7 does actually exist.

Lemma 8 *Let $\alpha > 0$ and $\delta_* = -1 + [\text{Var}_{\delta}[\delta] + (1 + \mathbb{E}_{\delta}[\delta])^2]^{1/2}$. Then, for any type distribution with positive variance, the gain function $u : [\delta_{\min}, \delta_{\max}] \rightarrow [0, \infty)$, $u(\delta) = \alpha(\delta_* - \delta)^2$, satisfies the conditions of Lemma 7(i).*

¹⁴By Lemma 7(iv), $\mathbb{E}_{\delta_i, \delta_{-i}}[\pi_{-i}] = \mathbb{E}_{\delta_i}[\mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i]] = R - |\mathbb{E}_{\delta}[u_{\delta}(\delta)]|$.

Proof. See Appendix A. ■

Beside the quadratic gain function, which is unique except for the choice of α , there may be many others. However, with quadratic u the information requirement is fairly weak: Support, mean, and variance of the type distribution need to be common knowledge; its higher moments, or even the distribution itself, need not be known. Generally, the information requirement should be as weak as possible. Consequently, in the remainder of this section, attention is restricted to the quadratic gain function of Lemma 8. Notice, however, that each of the Propositions of sections 3 and 4 is equally valid for any gain function satisfying the conditions of Lemma 7(i).

An interim-efficient screening contract \mathbb{W}^s in the form of (13) can now be derived on the grounds of Lemmas 6 to 8. Let

$$v(m_i, m_{-i}) = g(m_i) + z(m_i) - z(m_{-i}) \quad (16)$$

for sufficiently smooth functions $g, z : [0, \infty) \rightarrow \mathbb{R}$. As shown in Appendix B, the conditions of Lemma 7 imply that v necessarily takes the form of (17) below. This yields a screening contract that interim Pareto dominates the status quo in PBE and takes the agents' limited liability constraint into account.

Proposition 9 *Let $u(\delta) = \alpha(\delta_* - \delta)^2$ the gain function of Lemma 8. Suppose the principal can commit herself to implement the agents' contract choices after having learned the agents' types. Then, for any $\alpha > 0$, the menu of contracts $\mathbb{W}^s = \{w[m_i, m_{-i}](x_i, x_{-i})\}$, where*

$$w[m_i, m_{-i}](x_i, x_{-i}) = \begin{cases} v(m_i, m_{-i}) + x^* & , \text{ if } x_i = x^* \\ 0 & , \text{ else} \end{cases}$$

$$v(m_i, m_{-i}) = -\mathbb{E}_\delta[u_\delta(\delta)] + u(m_i) - m_i u_\delta(m_i) + u_\delta(m_{-i}), \quad (17)$$

interim Pareto dominates the status quo in PBE. The principal chooses the maximum value of α that meets with the agents' limited liability for any feasible composition of types.

Proof. See Appendix A. ■

Preferences for the composition of types at work are as follows.

Proposition 10 *Under interim-efficient screening according to \mathbb{W}^s from Proposition 9, each social type prefers a more altruistic over a less altruistic coworker. There exists for each type δ_i a critical type $\tau(\delta_i)$ such that δ_i 's ex post utility from ending up with a type δ_{-i} is smaller*

(greater) than his expected utility from \mathbb{W}^s if $\delta_{-i} <(>) \tau(\delta_i)$. The principal prefers less altruistic over more altruistic workers. She makes profits if agents are sufficiently spiteful ($\delta_i, \delta_{-i} \ll \delta_{\max}$), and losses if agents are sufficiently altruistic ($\delta_i, \delta_{-i} \gg \delta_{\min}$).

Proof. See Appendix A. ■

Proposition 10 implies that, as each party may ex post be worse off than expected *ex interim*, agents and principal effectively play a gamble over the composition of social types at work. Furthermore, it is straight forward to show that under interim-efficient screening according to Proposition 9, a type δ 's individual wealth $\pi(\delta, \tau)$ from a specific realization of his coworker's type τ satisfies $\partial\pi(\delta, \tau)/\partial\tau > 0$ and $\partial\pi(\delta, \delta)/\partial\delta > 0$. In this respect, interim-efficient screening involves the agents in a strategic game the distributive effects of which are closely related to the hawk-dove game.

The major caveat that can be brought up against the economic relevance of interim-efficient screening is the requisite of the principal's perfect commitment: implementation of interim-efficient screening requires the principal to hold up her contractual offer regardless of the realization of social types, even if she concludes from the agents' choices from the menu of contracts, and before production takes place, that she would end up making a loss as to her reservation profit in the status quo. From a real-world point of view, the principal's promise to hold up her contractual offer for any realization of social types would hardly be reliable. Interim-efficient pooling, instead, allows her to raise a positive ex ante expected profit and, at the same time, serves as a commitment device for the principal.

5 Interim-Efficient Pooling

This section characterizes pooling contracts that interim Pareto dominate the status quo in PBE. Again, necessary conditions are derived first. These conditions are then met with sufficient conditions.

Suppose that the principal cannot commit herself to implement the agents' choices from a menu of contracts (at stage 6*). By Proposition 5, she is then unable to provide herself with a positive (expected) profit by screening the agents. It is shown in the following that, in this case, she will offer a pooling contract that distorts the incentives to work and, thereby, incentivizes each agent to reveal his social type through the effort he exerts. Interim-efficient pooling then interim Pareto dominates the status quo in PBE.

The principal offers a single, symmetric contract $W^p = [w^p(x_i, x_{-i}), w^p(x_{-i}, x_i)]$, where the wage incentive scheme $w^p : [0, \infty)^2 \rightarrow [0, \infty)$ is twice partially continuously differentiable in x_i and x_{-i} . Again, attention is restricted to dominant strategy implementation: W^p

provides every type $\delta \in [\delta_{\min}, \delta_{\max}]$ with a dominant strategy effort $x(\delta) \geq 0$. The *type-effort correspondence* $x : [\delta_{\min}, \delta_{\max}] \rightarrow [0, \infty)$ maps each δ type onto this type's dominant strategy effort $x(\delta)$. By assumption, x is continuously differentiable and strictly monotone: either $x_\delta(\delta) > 0$, or $x_\delta(\delta) < 0$, for all $\delta \in [\delta_{\min}, \delta_{\max}]$. Strict monotonicity ensures that dominant strategy efforts differ across types.

Assume for the moment that there is a pooling contract W^P that does allow for interim Pareto improvement upon the status quo. Then P chooses W^P in order to maximize

$$\begin{aligned} \mathbb{E}_{\delta_i, \delta_{-i}}[\pi_P] &= \mathbb{E}_{\delta_i, \delta_{-i}}[x(\delta_i) + x(\delta_{-i}) - w^P(x(\delta_i), x(\delta_{-i})) - w^P(x(\delta_{-i}), x(\delta_i))] \\ &= 2\mathbb{E}_{\delta_i}[x(\delta_i)] - 2\mathbb{E}_{\delta_i}[\mathbb{E}_{\delta_{-i}}[w^P(x(\delta_i), x(\delta_{-i}))]], \end{aligned} \quad (18)$$

with the type-effort correspondence $x : [\delta_{\min}, \delta_{\max}] \rightarrow [0, \infty)$. Then agent i 's interim expected utility from implementation of W^P , given his belief that agent $-i$ of type $\delta_{-i} \sim F$ would accept W^P , must satisfy

$$\begin{aligned} \mathbb{E}_{\delta_{-i}}[U_i[\delta_i; x(\delta_i), x(\delta_{-i})]] &= \mathbb{E}_{\delta_{-i}}[w^P(x(\delta_i), x(\delta_{-i})) - C(x(\delta_i))] \\ &\quad + \delta_i \mathbb{E}_{\delta_{-i}}[w^P(x(\delta_{-i}), x(\delta_i)) - C(x(\delta_{-i}))] \\ &= (1 + \delta_i)R + u(\delta_i) \end{aligned} \quad (19)$$

for some real number $u(\delta_i) \geq 0$. Again, the mapping $u : [\delta_{\min}, \delta_{\max}] \rightarrow [0, \infty)$ is referred to as the *gain function*.

Lemma 11 *Suppose there is a pooling contract $W^P = [w^P(x_i, x_{-i}), w^P(x_{-i}, x_i)]$, with $w : [0, \infty)^2 \rightarrow [0, \infty)$ twice partially continuously differentiable, that provides each type $\delta \in [\delta_{\min}, \delta_{\max}]$ with a strictly dominant effort strategy $x(\delta) \geq 0$, where $x : [\delta_{\min}, \delta_{\max}] \rightarrow [0, \infty)$ is continuously differentiable and strictly monotone. Suppose further that W^P interim Pareto dominates the status quo in PBE by implementing expected utilities $\mathbb{E}_{\delta_{-i}}[U_i[\delta_i; x(\delta_i), x(\delta_{-i})]] = (1 + \delta_i)R + u(\delta_i)$, with $u(\delta_i) \geq 0$ at each δ_i . Then the following holds necessarily:*

(i) *The gain function $u : [\delta_{\min}, \delta_{\max}] \rightarrow [0, \infty)$ is twice differentiable and strictly convex. It satisfies $\mathbb{E}_\delta[u_\delta(\delta)] < 0$ and $\mathbb{E}_\delta[u(\delta)] = \mathbb{E}_\delta[(1 + \delta)u_\delta(\delta)]$.*

(ii) *The principal has an ex ante expected profit of*

$$\mathbb{E}_{\delta_i, \delta_{-i}}[\pi_P] = 2|\mathbb{E}_\delta[u_\delta(\delta)]| + 2(\mathbb{E}_\delta[x(\delta) - C(x(\delta))] - R).$$

(iii) *Type δ_i has an interim expected wealth of $\mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] = R + u(\delta_i) - \delta_i u_\delta(\delta_i)$.*

(iv) Type δ_i expects ex interim a wealth of $\mathbb{E}_{\delta_{-i}}[\pi_{-i}|\delta_i] = R + u_\delta(\delta_i)$ for coworker $-i$.

Proof. See Appendix A. ■

Except for the principal's profit, the necessary conditions stated by Lemma 11 are exactly the same as those derived for interim-efficient screening, given by Lemma 7. Hence, each social type can be made indifferent between interim-efficient screening and interim-efficient pooling. In particular, the gain function of Lemma 8 qualifies for interim-efficient pooling.

By Lemma 11(ii), the principal's expected profit is separable in the extent of aggregate redistribution, $2|\mathbb{E}_\delta[u_\delta(\delta)]|$, and a measure for the expected inefficiency of production, $\mathbb{E}_\delta[x(\delta) - C(x(\delta))] - R$. Under interim-efficient pooling, production is necessarily inefficient: $\mathbb{E}_\delta[x(\delta) - C(x(\delta))] < R$.¹⁵ In particular, the screening contract \mathbb{W} of Proposition 9 interim Pareto dominates any interim-efficient pooling contract that implements the same gain function u . This highlights the social costs involved with the principal's imperfect commitment and thereby establishes a 'ratchet effect' (Laffont and Tirole 1988) in the range of asymmetric information on other-regarding preferences.

Presume for the moment the existence of a type-effort correspondence x satisfying the assumptions and conditions of Lemma 11. An interim-efficient pooling contract can now be derived on the grounds of Lemmas 8 and 11. Let

$$w^p(x_i, x_{-i}) = v(x_i) + z(x_i) - z(x_{-i}) \quad (20)$$

for sufficiently smooth functions $v, z : [0, \infty) \rightarrow \mathbb{R}$. As shown in Appendix B, the conditions of Lemma 11 imply that w^p necessarily takes the form of (21) below. This yields a pooling contract that interim Pareto dominates the status quo in PBE.

Proposition 12 *Let $u(\delta) = \alpha(\delta_* - \delta)^2$ the gain function of Lemma 8. Suppose the function $x : [\delta_{\min}, \delta_{\max}] \rightarrow [0, \infty)$ is continuously differentiable, strictly monotone, and satisfies $\mathbb{E}_\delta[x(\delta) - C(x(\delta))] > R - |\mathbb{E}_\delta[u_\delta(\delta)]|$. Denote by $h : [\underline{x}, \bar{x}] \rightarrow [\delta_{\min}, \delta_{\max}]$ the inverse of x . Then, for any $\alpha > 0$, the pooling contract $W^p = [w^p(x_i, x_{-i}), w^p(x_{-i}, x_i)]$, with*

$$\begin{aligned} w^p(x_i, x_{-i}) &= R - \mathbb{E}_\delta[u_\delta(\delta)] \\ &\quad + C(x_i) + u(h(x_i)) - h(x_i)u_\delta(h(x_i)) \\ &\quad + u_\delta(h(x_{-i})), \end{aligned} \quad (21)$$

interim Pareto dominates the status quo in PBE. It provides each type δ_i with the strictly dominant effort strategy $x(\delta_i)$. If x increases (decreases) in δ_i , then W^p imposes a positive

¹⁵Otherwise, if $\mathbb{E}_\delta[x(\delta) - C(x(\delta))] = R - C(x^*)$, almost all agents are required to exert the efficient effort x^* , making all information asymmetry effectively irrelevant.

(negative) externality of every agent's effort on his coworker's pay. The principal chooses the maximum value of α that meets with the agents' limited liability for any feasible composition of types.

Proof. See Appendix A. ■

The interim-efficient pooling contract (21) consists of a fixed salary, an individual performance component, and an externality component either specifying relative or team performance incentives. Notice that the individual performance component entails direct compensation for the individual costs of effort. Except for coworkers of identical type, interim-efficient pooling leads to wage inequality the extent of which is determined by the scalar α . *Ex interim*, as indicated by Lemmas 7 and 10, principal and agents unanimously favor a strong extent of potential inequality. However, the agents' limited liability requests that ex post inequality is bounded.

With Proposition 12, the specification of an interim-efficient pooling contract simplifies to the task of identifying a continuously differentiable, strictly monotone function x satisfying $\mathbb{E}_\delta [x(\delta) - C(x(\delta))] > R - |\mathbb{E}_\delta [u_\delta(\delta)]|$. Notice that it does not matter whether x is increasing or decreasing, even though interim-efficient pooling provides the agents with team performance incentives in one case and with relative performance incentives in the other.

Proposition 13 *There exist infinitely many (ex interim payoff equivalent) pooling contracts that interim Pareto dominate the status quo in PBE. Interim-efficient pooling implements either relative or team performance pay in a payoff equivalent way.*

Proof. See Appendix A. ■

Since the type space was taken arbitrary, team performance pay according to W^P is interim-efficient even if all types are spiteful, $\delta_{\max} < 0$, and relative performance pay is interim-efficient even if all types are altruistic, $\delta_{\min} > 0$. Preferences for the composition of social types at work are as follows.

Proposition 14 *Under interim-efficient pooling according to W^P of Proposition 12, each social type prefers a more altruistic over a less altruistic coworker. There exists for each type δ_i a critical type $\tau(\delta_i)$ such that type δ_i 's ex post utility from ending up with a type δ_{-i} is smaller (greater) than his expected utility from W^P if $\delta_{-i} < (>) \tau(\delta_i)$. The principal prefers less altruistic over more altruistic workers if the type-effort correspondence x is chosen such that $|x_\delta(\delta)|$ is bounded. In this case, the principal makes positive profits if agents are sufficiently spiteful (i.e., $\delta_i, \delta_{-i} \ll \delta_{\max}$), and losses if agents are sufficiently altruistic (i.e., $\delta_i, \delta_{-i} \gg \delta_{\min}$).*

Proof. See Appendix A. ■

By Proposition 14, and similar to interim-efficient screening, each party may be worse off ex post than expected *ex interim*, such that agents and principal effectively play a gamble over the composition of social types at work. In addition, it is easy to show that interim-efficient pooling, too, involves the agents in a strategic game the distributive effects of which are closely related to the hawk-dove game: a type δ 's individual wealth $\pi(\delta, \tau)$ from a specific realization of his coworker's type τ satisfies $\partial\pi(\delta, \tau)/\partial\tau > 0$ and $\partial\pi(\delta, \delta)/\partial\delta > 0$.

6 Examples of Interim-Efficient Relative and Team Performance Pay

This section derives and illustrates two particular interim-efficient pooling contracts, one implementing relative performance pay, the other one team performance pay. It shows in particular that, and how, the principal, when being constrained to imperfect commitment, can approximate the 'first-best' interim efficient allocation implemented by the menu of contracts of Proposition 9 arbitrarily closely by choosing the type-effort correspondence appropriately.

Let $\delta_{\min} = -1$ and $\delta_{\max} = 1$ in the following. For δ_* from Lemma 8, denote by

$$S(\alpha) = R + \alpha [1 + \delta_*^2 - 2\mathbb{E}_\delta[\delta]] \quad (22)$$

a constant that will specify a salary below. Relative performance pay is addressed first. For $\kappa \in (0, 1)$, consider the type-effort correspondence $x : [-1, 1] \rightarrow [0, x^*]$ with

$$x(\delta) = x^* \left(\frac{1 - \delta}{2} \right)^\kappa. \quad (23)$$

By choice of x , the interim-efficient pooling contract is supposed to incentivize the least altruistic type to produce efficiently, $x(-1) = x^*$, while it incentivizes all the other types to exert inefficiently low efforts. Notice that $\lim_{\kappa \rightarrow 0} x(\delta) = x^*$ for each $\delta < 1$. The inverse of x is given by $h : [0, x^*] \rightarrow [-1, 1]$, $h(x) = 1 - 2(x/x^*)^{\frac{1}{\kappa}}$. Plugging h and the gain function u from Lemma 8 into (21) yields a version of interim-efficient relative performance pay (RPP).¹⁶ By Proposition 12, for each $\alpha > 0$, the pooling contract $W_{RPP} = [w_{RPP}(x_i, x_{-i}), w_{RPP}(x_{-i}, x_i)]$,

¹⁶**Notation:** Let A and B two sets, with $A \subset B$. Then $1_A : B \rightarrow \{0, 1\}$ denotes the indicator function of A ; that is, $1_A(x) = 1$ if $x \in A$, and $1_A(x) = 0$ if $x \in B \setminus A$.

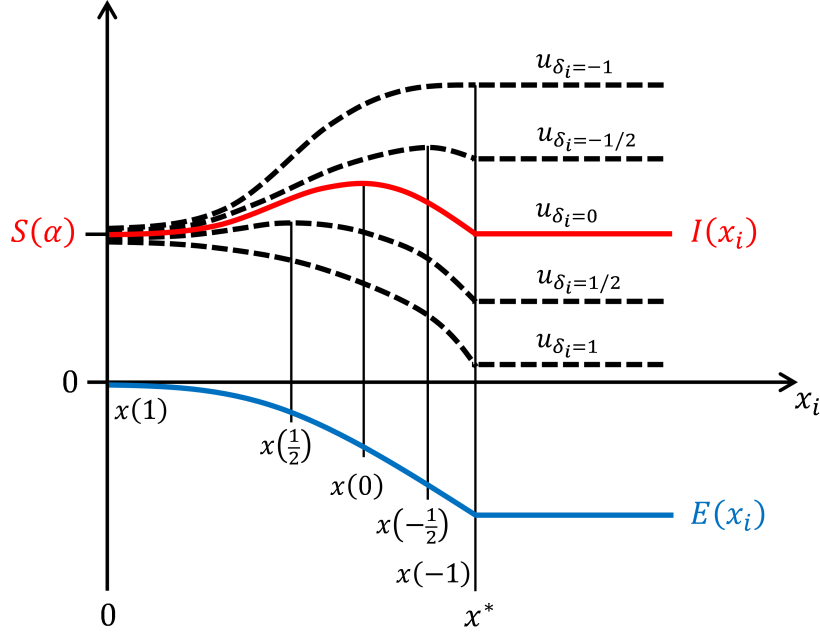


Figure 4: A stylized representation of how an agent's effort under W_{RPP} from (24) affects his own wealth, given by the effort internality $I(x_i)$, and how it affects his coworker's wealth, given by the effort externality $E(x_i)$. For $\delta_i \in \{-1, -\frac{1}{2}, 0, \frac{1}{2}, 1\}$, the dashed curves $u[\delta_i](x_i) = I(x_i) + \delta_i E(x_i)$ show how type δ_i 's effort choice directly affects his utility; maximum utility is achieved at the dominant strategy effort level $x(\delta_i)$ determined by (23).

with

$$w_{RPP}(x_i, x_{-i}) = S(\alpha) + C(x_i) + 4\alpha[1 - V_{RPP}(x_i)]V_{RPP}(x_i) - 4\alpha V_{RPP}(x_{-i}) \quad (24)$$

and $V_{RPP}(x) = 1_{[0, x^*]}(x) [x/x^*]^{\frac{1}{\kappa}}$, interim Pareto dominates the status quo in PBE if κ is taken sufficiently small. The agents' limited liability constraints are satisfied if $\alpha > 0$ is taken sufficiently small.

Figure 4 gives a stylized illustration of relative performance pay according to (24). It depicts how an agent i 's individual effort under W_{RPP} affects his own wealth, given by the effort internality $I(x_i) = S(\alpha) + 4\alpha[1 - V_{RPP}(x_i)]V_{RPP}(x_i)$, and how his effort affects his coworker's wealth, given by the effort externality $E(x_i) = -4\alpha V_{RPP}(x_i)$. For $\delta_i \in \{-1, -\frac{1}{2}, 0, \frac{1}{2}, 1\}$, the dashed curves $u[\delta_i](x_i) = I(x_i) + \delta_i E(x_i)$ show how a type δ_i 's effort choice directly affects his expected utility.¹⁷

For an example of team performance pay, denote by \bar{x} the unique solution of $x - C(x) =$

¹⁷Since $\mathbb{E}[u_i(x_i) | \delta_i] = u[\delta_i](x_i) + \mathbb{E}[E(x(\tau)) + \delta_i I(x(\tau))]$, expected utility maximization is equivalent to the maximization of $u[\delta_i](x_i)$.

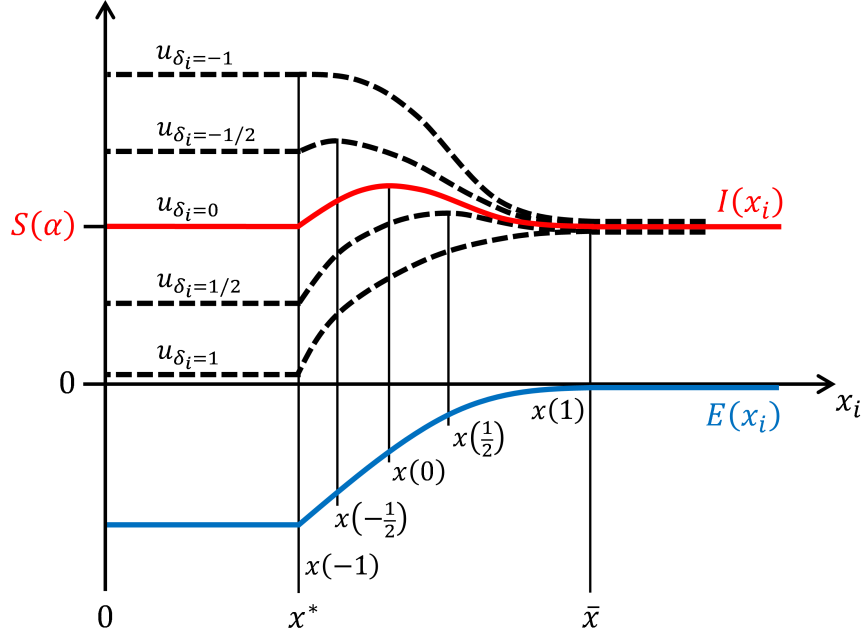


Figure 5: A stylized representation of how an agent's effort under W_{TPP} from (26) affects his own wealth, given by the effort internality $I(x_i)$, and how it affects his coworker's wealth, given by the effort externality $E(x_i)$. For $\delta_i \in \{-1, -\frac{1}{2}, 0, \frac{1}{2}, 1\}$, the dashed curves $u[\delta_i](x_i) = I(x_i) + \delta_i E(x_i)$ show how type δ_i 's effort choice directly affects his utility; maximum utility is achieved at the dominant strategy effort level $x(\delta_i)$, given by (25).

$-2(\delta_* - \mathbb{E}_\delta[\delta])$. Since $\delta_* > \mathbb{E}_\delta[\delta]$, we have $\bar{x} \in (x^*, \infty)$. For $\kappa \in (0, 1)$, consider the type-effort correspondence $x : [-1, 1] \rightarrow [x^*, \bar{x}]$ with

$$x(\delta) = \bar{x} - (\bar{x} - x^*) \left(\frac{1 - \delta}{2} \right)^\kappa. \quad (25)$$

By choice of x , the interim-efficient pooling contract is supposed to incentivize the least altruistic type to produce efficiently, while it incentivizes all the other types to exert inefficiently high efforts. Notice that $\lim_{\kappa \rightarrow 0} x(\delta) = x^*$ for each $\delta < 1$. The inverse of x is $h : [0, x^*] \rightarrow [-1, 1]$, with $h(x) = 1 - 2 \left[\frac{(\bar{x} - x)}{(\bar{x} - x^*)} \right]^{\frac{1}{\kappa}}$. Plugging h and the gain function u of Lemma 8 into (21) yields a version of interim-efficient team performance pay (TPP). By Proposition 12, for each $\alpha > 0$, the pooling contract $W_{TPP} = [w_{TPP}(x_i, x_{-i}), w_{TPP}(x_{-i}, x_i)]$, with

$$w_{TPP}(x_i, x_{-i}) = S(\alpha) + C(x_i) + 4\alpha [1 - V_{TPP}(x_i)] V_{TPP}(x_i) - 4\alpha V_{TPP}(x_{-i}) \quad (26)$$

and $V_{TPP}(x) = 1_{[x^*, \bar{x}]}(x) \left[\frac{(\bar{x} - x)}{(\bar{x} - x^*)} \right]^{\frac{1}{\kappa}}$, interim Pareto dominates the status quo in

PBE if κ is taken sufficiently small. The agents' limited liability constraints are satisfied if $\alpha > 0$ is taken sufficiently small.

Figure 5 gives a stylized illustration of team performance pay according to (26). It depicts how an agent i 's individual effort under W_{TPP} affects his own wealth, given by the effort internality $I(x_i) = S(\alpha) + 4\alpha[1 - V_{TPP}(x_i)]V_{TPP}(x_i)$, how his effort affects his coworker's wealth, given by the effort externality $E(x_i) = -4\alpha V_{TPP}(x_i)$, and, for $\delta_i \in \{-1, -\frac{1}{2}, 0, \frac{1}{2}, 1\}$, how i 's effort choice directly effects his interim expected utility given his type δ_i .

7 Conclusion

This study rationalizes that a company's organizational climate has a random component associated with workers' intrinsic motivations to collaborate or to compete, potentially leading to dissatisfaction on the job. If, before contracting, workers are privately informed about the extent to which they internalize the externalities that their actions impose on coworkers, then interim-efficient contracting involves workers to voluntarily expose themselves to the risk of ending up with less cooperative, or more competitive, coworkers. This finding is in line with the empirical observation that workers' perceived support from coworkers is a key factor for job satisfaction and labor turnover.

Generally, the findings indicate that asymmetric information on people's social preferences is not necessarily a matter of 'adverse' selection. When met with appropriate incentives, its effects can, *ex interim*, be mutually beneficial rather than adverse. To this extent, social preferences involve their own economics of information.

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A Omitted Proofs

Proof of Lemma 1. The proof consists of three parts. It is shown that (i) any contract \bar{W} that does not incentivize individual effort x^* is Pareto-dominated by a contract W' that does incentivize individual effort x^* while distributing the returns from total output among $\{P, i, -i\}$ appropriately, (ii) any distribution of the market returns from total output, regardless how large, among $\{P, i, -i\}$ is Pareto-efficient, and (iii) W^* is Pareto-efficient.

Ad (i). Suppose P uses a contract \bar{W} that incentivizes agents $i, -i$ to exert efforts \bar{x}_i, \bar{x}_{-i} and pays them wages \bar{w}_i, \bar{w}_{-i} . Utilities and profits associated with \bar{W} can be written

$$\begin{aligned}\bar{u}_i &= [(\bar{w}_i - \bar{x}_i) + (\bar{x}_i - C(\bar{x}_i))] + \delta_i [(\bar{w}_{-i} - \bar{x}_{-i}) + (\bar{x}_{-i} - C(\bar{x}_{-i}))], \\ \bar{u}_{-i} &= [(\bar{w}_{-i} - \bar{x}_{-i}) + (\bar{x}_{-i} - C(\bar{x}_{-i}))] + \delta_{-i} [(\bar{w}_i - \bar{x}_i) + (\bar{x}_i - C(\bar{x}_i))], \\ \bar{\pi}_P &= -(\bar{w}_i - \bar{x}_i) - (\bar{w}_{-i} - \bar{x}_{-i}).\end{aligned}\tag{27}$$

The mapping $x \mapsto x - C(x)$ is unimodular and maximal at $x^* = C_x^{-1}(1)$. Hence, if $\bar{x}_i \neq x^*$, there exists $\bar{\varepsilon}_i > 0$ such that $x^* - C(x^*) = \bar{x}_i - C(\bar{x}_i) + \bar{\varepsilon}_i$; similarly for $-i$. The contract $W' = [w'_i(x_i, x_{-i}), w'_{-i}(x_{-i}, x_i)] = [\bar{w}_i - \bar{x}_i - \bar{\varepsilon}_i + x_i, \bar{w}_{-i} - \bar{x}_{-i} - \bar{\varepsilon}_{-i} + x_{-i}]$ interim Pareto dominates \bar{W} : Each agent i maximizes his utility $U_i = [\bar{w}_i - \bar{x}_i - \bar{\varepsilon}_i + x_i - C(x_i)] + \delta_i [\bar{w}_{-i} - \bar{x}_{-i} - \bar{\varepsilon}_{-i} + x_{-i} - C(x_{-i})]$ by exerting the effort $x_i = x^*$. When comparing utilities and profits under W' with those under \bar{W} , given by (27), we find

$$\begin{aligned}U'_i &= [\bar{w}_i - \bar{x}_i - \bar{\varepsilon}_i + x^* - C(x^*)] + \delta_i [\bar{w}_{-i} - \bar{x}_{-i} - \bar{\varepsilon}_{-i} + x^* - C(x^*)] \\ &= [\bar{w}_i - \bar{x}_i - \bar{\varepsilon}_i + \bar{x}_i - C(\bar{x}_i) + \bar{\varepsilon}_i] + \delta_i [\bar{w}_{-i} - \bar{x}_{-i} - \bar{\varepsilon}_{-i} + \bar{x}_{-i} - C(\bar{x}_{-i}) + \bar{\varepsilon}_{-i}] \\ &= [\bar{w}_i - C(\bar{x}_i)] + \delta_i [\bar{w}_{-i} - C(\bar{x}_{-i})] \\ &= \bar{U}_i.\end{aligned}\tag{28}$$

Similarly, $U'_{-i} = \bar{U}_{-i}$. On the other hand,

$$\begin{aligned}\pi'_P &= [x^* - (\bar{w}_i - \bar{x}_i - \bar{\varepsilon}_i + x^*)] + [x^* - (\bar{w}_{-i} - \bar{x}_{-i} - \bar{\varepsilon}_{-i} + x^*)] \\ &= \bar{\varepsilon}_i - (\bar{w}_i - \bar{x}_i) + \bar{\varepsilon}_{-i} - (\bar{w}_{-i} - \bar{x}_{-i}) \\ &= \bar{\pi}_P + \bar{\varepsilon}_i + \bar{\varepsilon}_{-i} \\ &> \bar{\pi}_P.\end{aligned}\tag{29}$$

Therefore, efficient contracting under complete information incentivizes each agent, regardless of his social type, to exert the effort x^* .

Ad (ii). Suppose that, for some commonly known composition of social types $(\delta_i, \delta_{-i}) \in [\delta_{\min}, \delta_{\max}]^2$, the contract $W = [w_i(x_i, x_{-i}), w_{-i}(x_{-i}, x_i)]$ incentivizes efficient production, and consider some distribution $\pi_P + w_i + w_{-i} = 2x^*$ of the respective market returns among $\{P, i, -i\}$. By (i), individual efforts are identical, such that effort costs can, without loss of generality, be suppressed in the following. The agents' utilities from their wage payments are $U_i = w_i + \delta_i w_{-i}$ and $U_{-i} = w_{-i} + \delta_{-i} w_i$. Suppose there is a redistribution of wealth, $\pi'_P + w'_i + w'_{-i} = x$, such that $\pi'_P \geq \pi_P$, while there exist $v_i, v_{-i} \geq 0$ such that both

$$\begin{aligned} U'_i &= w'_i + \delta_i w'_{-i} = w_i + \delta_i w_{-i} + v_i, \\ U'_{-i} &= \pi'_{-i} + \delta_{-i} \pi'_i = w_{-i} + \delta_{-i} w_i + v_{-i}, \end{aligned} \quad (30)$$

and that at least one of the inequalities $\pi'_P - \pi_P, v_i, v_{-i} \geq 0$ is strict. Let $\mathbf{w} = (w_i, w_{-i})^T$, $\mathbf{w}' = (w'_i, w'_{-i})^T$, $\mathbf{v} = (v_i, v_{-i})^T$, $\mathbf{1} = (1, 1)^T$, and

$$\mathbf{\Delta} = \begin{pmatrix} 1 & \delta_i \\ \delta_{-i} & 1 \end{pmatrix}. \quad (31)$$

By (30), $\mathbf{\Delta} \mathbf{w}' = \mathbf{\Delta} \mathbf{w} + \mathbf{v}$, where $\mathbf{\Delta}$ is invertible. Hence, $\mathbf{w}' = \mathbf{w} + \mathbf{\Delta}^{-1} \mathbf{v}$. Furthermore, $\pi_P = x - \mathbf{1}^T \mathbf{w}$ and $\pi'_P = x - \mathbf{1}^T \mathbf{w}'$. Therefore,

$$\pi'_P = x - \mathbf{1}^T \mathbf{w}' = x - \mathbf{1}^T \mathbf{w} - \mathbf{1}^T \mathbf{\Delta}^{-1} \mathbf{v} = \pi_P - \mathbf{1}^T \mathbf{\Delta}^{-1} \mathbf{v}. \quad (32)$$

Since $v_i, v_{-i} \geq 0$ and $\delta_i, \delta_{-i} \in (-1, 1)$, we have

$$\begin{aligned} \mathbf{1}^T \mathbf{\Delta}^{-1} \mathbf{v} &= \frac{1}{1 - \delta_i \delta_{-i}} (1, 1) \begin{pmatrix} 1 & -\delta_i \\ -\delta_{-i} & 1 \end{pmatrix} \begin{pmatrix} v_i \\ v_{-i} \end{pmatrix} \\ &= \frac{1}{1 - \delta_i \delta_{-i}} [(1 - \delta_{-i}) v_i + (1 - \delta_i) v_{-i}] \\ &\geq 0, \end{aligned} \quad (33)$$

where $\mathbf{1}^T \mathbf{\Delta}^{-1} \mathbf{v} = 0$ if and only if $v_i, v_{-i} = 0$. By (32) and (33), Pareto improvement requires $\pi_P \leq \pi'_P = \pi_P - \mathbf{1}^T \mathbf{\Delta}^{-1} \mathbf{v} \leq \pi_P$. Hence, $\pi'_P = \pi_P$ and $\mathbf{1}^T \mathbf{\Delta}^{-1} \mathbf{v} = 0$; thus, $v_i, v_{-i} = 0$. Therefore, any redistribution of the returns from production among $\{P, i, -i\}$ is Pareto efficient.

Ad (iii). Under W^* agent i of type δ_i maximizes utility $u_i = x_i - C(x_i) + \delta_i [x_{-i} - C(x_{-i})]$ by exerting the effort $x_i = x^*$. Hence, by (i), W^* implements efficient production. By (ii), the respective allocation $[\pi_P, U_i, U_{-i}] = [0, (1 + \delta_i) R, (1 + \delta_{-i}) R]$, where $R = x^* - C(x^*)$, is Pareto efficient. ■

Proof of Lemma 4. Suppose there exists a contract menu \mathbb{W} that interim Pareto dominates the status quo, with positive ex ante expected profit for P , while guaranteeing P a non-negative ex post profit for any realization of social types. Consider some realization δ_i, δ_{-i} . Denote by x_i the ex post effort, by w_i the ex post wage, and by $\pi_i = w_i - C(x_i)$ the ex post wealth of agent i implemented by \mathbb{W} , all contingent on δ_i, δ_{-i} . The principal's ex post profit then satisfies $\pi_P = R_i - \pi_i + R_{-i} - \pi_{-i}$, where $R_i = x_i - C(x_i) \leq R$. By assumption, P makes no loss ex post: $\pi_P \geq 0$. Furthermore, $0 < \mathbb{E}_{\delta_i, \delta_{-i}}[\pi_P] = \mathbb{E}_{\delta_i, \delta_{-i}}[R_i - \pi_i + R_{-i} - \pi_{-i}] \leq 2R - \mathbb{E}_{\delta_i, \delta_{-i}}[\pi_i + \pi_{-i}]$, where $\mathbb{E}_{\delta_i, \delta_{-i}}[\pi_i + \pi_{-i}] = \mathbb{E}_{\delta_i}[\mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] + \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i]]$. Hence, \mathbb{W} jointly satisfies the following conditions: For all i and δ_i ,

$$2R \geq \pi_i + \pi_{-i}, \quad (34a)$$

$$2R > \mathbb{E}_{\delta_i}[\mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] + \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i]], \quad (34b)$$

$$(1 + \delta_i)R \leq \mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] + \delta_i \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i] = \mathbb{E}_{\delta_{-i}}[U_i | \delta_i]. \quad (34c)$$

Conditions (34a) and (34b) imply that there exists a non-null set $A \subseteq [\delta_{\min}, \delta_{\max}]$, such that $2R > \mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] + \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i]$ for all $\delta_i \in A$, while $2R = \mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] + \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i]$ for all $\delta_i \in [\delta_{\min}, \delta_{\max}] \setminus A$.

In the following, the symbol \geq_A indicates that the inequality holds for any $\delta_i \in [\delta_{\min}, \delta_{\max}]$ while it is necessarily strict if $\delta_i \in A$. Hence, $2R \geq_A \mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] + \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i]$.

Show first that the system (34a)-(34c) implies $\mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] \geq_A \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i]$. From (34c) and $2R \geq_A \mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] + \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i]$, respectively, we have

$$\delta_i \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i] \geq (1 + \delta_i)R - \mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] \geq_A - (1 - \delta_i)R + \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i], \quad (35)$$

which yields $(1 - \delta_i)R \geq_A (1 - \delta_i) \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i]$; thus, $R \geq_A \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i]$. This implies $\mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] \geq_A R \geq_A \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i]$ for all $\delta_i > 0$. Now consider types $\delta_i \leq 0$. Trivially, $\mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] \geq R \geq_A \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i]$ for all those $\delta_i \leq 0$ with $\mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] \geq R$. By (34c), $\mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] \geq R$ is satisfied for $\delta_i = 0$. On the other hand, if $\mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] < R$ for some $\delta_i < 0$, then (34c) implies that

$$\mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] \geq (1 + \delta_i)R + |\delta_i| \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i] > (1 + \delta_i) \mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] + |\delta_i| \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i], \quad (36)$$

which yields $|\delta_i| \mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] > |\delta_i| \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i]$; thus, $\mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] > \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i]$ for all those $\delta_i < 0$ with $\mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] < R$. Hence, $\mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] \geq_A \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i]$ for all $\delta_i \leq 0$. Summing up, interim Pareto improvement upon the status quo, with non-negative ex post profit for P , implies $\mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] \geq_A \mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i]$ for all $\delta_i \in [\delta_{\min}, \delta_{\max}]$.

From an ex ante perspective, we thus have $\mathbb{E}_{\delta_i}[\mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i]] > \mathbb{E}_{\delta_i}[\mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i]]$, where

inequality is now necessarily strict, since A is non-null. By the law of total expectation, $\mathbb{E}_{\delta_i, \delta_{-i}} [\pi_i] = \mathbb{E}_{\delta_i} [\mathbb{E}_{\delta_{-i}} [\pi_i | \delta_i]]$ and $\mathbb{E}_{\delta_{-i}, \delta_i} [\pi_{-i}] = \mathbb{E}_{\delta_{-i}} [\mathbb{E}_{\delta_i} [\pi_{-i} | \delta_{-i}]]$. Hence, $\mathbb{E}_{\delta_i, \delta_{-i}} [\pi_i] > \mathbb{E}_{\delta_{-i}, \delta_i} [\pi_{-i}]$. That is, from an ex ante perspective, an agent who is labeled i expects to be materially better off than his coworker labeled $-i$. With labels exchanged, we also have $\mathbb{E}_{\delta_{-i}, \delta_i} [\pi_{-i}] > \mathbb{E}_{\delta_i, \delta_{-i}} [\pi_i]$; that is, an agent labeled $-i$ expects to be materially better off than his coworker labeled i . This contradicts the assumption that \mathbb{W} is publicly observable before contracting and the requisite that types are *iid* and form rational and mutually consistent beliefs in PBE; the argument builds on Aumann (1976). ■

Proof of Lemma 7. *Ad (i):* By assumption, \mathbb{W}^s incentivizes each agent to exert the efficient effort level x^* and implements truthful revelation of social types in (some) PBE. In this PBE, an agent i of type δ_i , when sending the message $m_i \in [\delta_{\min}, \delta_{\max}]$, thus expects utility

$$\mathbb{E}_{\delta_{-i}} [U_i [\delta_i; m_i, \delta_{-i}, x^*, x^*]] = \mathbb{E}_{\delta_{-i}} [R + v(m_i, \delta_{-i})] + \delta_i \mathbb{E}_{\delta_{-i}} [R + v(\delta_{-i}, m_i)]. \quad (37)$$

Since $v(m_i, \delta_{-i})$ is twice partially continuously differentiable in m_i , also $\mathbb{E}_{\delta_{-i}} [U_i(m_i) | \delta_i]$ is twice continuously differentiable in m_i ; in particular, Leibniz' rule for differentiation under the integral sign is applicable. Since, by assumption, \mathbb{W}^s implements truthful revelation in PBE, the first-order condition (*FOC*)

$$0 = \frac{d}{dm_i} \mathbb{E}_{\delta_{-i}} [U_i [\delta_i; m_i, \delta_{-i}, x^*, x^*]] \Big|_{m_i=\delta_i} \quad (38)$$

and the second-order conditon (*SOC*)

$$0 > \frac{d^2}{dm_i^2} \mathbb{E}_{\delta_{-i}} [U_i [\delta_i; m_i, \delta_{-i}, x^*, x^*]] \Big|_{m_i=\delta_i} \quad (39)$$

must be satisfied for all i and δ_i . Hence, for all i and δ_i ,

$$0 = \mathbb{E}_{\delta_{-i}} [v_1(\delta_i, \delta_{-i}) + \delta_i v_2(\delta_{-i}, \delta_i)], \quad (40)$$

$$0 > \mathbb{E}_{\delta_{-i}} [v_{11}(\delta_i, \delta_{-i}) + \delta_i v_{22}(\delta_{-i}, \delta_i)]. \quad (41)$$

Differentiating the *FOC* (40) with respect to δ_i yields

$$0 = \mathbb{E}_{\delta_{-i}} [v_2(\delta_{-i}, \delta_i)] + \mathbb{E}_{\delta_{-i}} [v_{11}(\delta_i, \delta_{-i}) + \delta_i v_{22}(\delta_{-i}, \delta_i)]. \quad (42)$$

The *SOC* (41) implies that $\mathbb{E}_{\delta_{-i}} [v_2(\delta_{-i}, \delta_i)] > 0$. By assumption, $\mathbb{E}_{\delta_{-i}} [U_i [\delta_i; \delta_i, \delta_{-i}, x^*, x^*]] =$

$(1 + \delta_i) R + u(\delta_i)$, where $\mathbb{E}_{\delta_{-i}} [U_i [\delta_i; \delta_i, \delta_{-i}, x^*, x^*]]$ is differentiable in δ_i given the assumptions on \mathbb{W}^s . Hence, also $u(\delta_i)$ is differentiable in δ_i . Differentiating (37) with respect to δ_i and evaluating at $\delta_i = \delta$ yields

$$\begin{aligned}
R + u_\delta(\delta) &= \left. \frac{d}{d\delta_i} \mathbb{E}_{\delta_{-i}} [U_i [\delta_i; \delta_i, \delta_{-i}, x^*, x^*]] \right|_{\delta_i=\delta} \\
&= \underbrace{\left. \frac{d}{dm_i} \mathbb{E}_{\delta_{-i}} [U_i [\delta_i; \delta_i, \delta_{-i}, x^*, x^*]] \right|_{m_i=\delta}}_{\stackrel{FOC_0}{=} 0} \cdot \left. \frac{dm_i}{d\delta_i} \right|_{\delta_i=\delta} + \mathbb{E}_{\delta_{-i}} [R + v(\delta_{-i}, \delta)] \\
&= \mathbb{E}_{\delta_{-i}} [R + v(\delta_{-i}, \delta)].
\end{aligned} \tag{43}$$

Hence, $\mathbb{E}_{\delta_{-i}} [v(\delta_{-i}, \delta)] = u_\delta(\delta)$. As $v(m_i, m_{-i})$ is partially differentiable in m_{-i} , Leibniz' rule implies that u_δ is differentiable in δ . Differentiating (43) with respect to δ yields

$$u_{\delta\delta}(\delta) = \mathbb{E}_{\delta_{-i}} [v_2(\delta_{-i}, \delta)]. \tag{44}$$

Since $\mathbb{E}_{\delta_{-i}} [v_2(\delta_{-i}, \delta)] > 0$ by (41) and (42), we have $u_{\delta\delta}(\delta) > 0$. Furthermore, taking expectations over $\delta \sim F$ in (43) yields

$$\mathbb{E}_\delta [u_\delta(\delta)] = \mathbb{E}_\delta [\mathbb{E}_{\delta_{-i}} [v(\delta_{-i}, \delta)]] = -\frac{1}{2} \mathbb{E}_{\delta_i, \delta_{-i}} [\pi_P]. \tag{45}$$

Hence, $\mathbb{E}_{\delta_i, \delta_{-i}} [\pi_P] = -2\mathbb{E}_\delta [u_\delta(\delta)]$. Since $\mathbb{E}_{\delta_i, \delta_{-i}} [\pi_P] > 0$ by assumption, $\mathbb{E}_\delta [u_\delta(\delta)] < 0$. Finally, (43) yields

$$\begin{aligned}
(1 + \delta) R + u(\delta) &= \mathbb{E}_{\delta_{-i}} [U_i [\delta; \delta, \delta_{-i}, x^*, x^*]] \\
&= \mathbb{E}_{\delta_{-i}} [R + v(\delta, \delta_{-i})] + \delta \mathbb{E}_{\delta_{-i}} [R + v(\delta_{-i}, \delta)] \\
&= \mathbb{E}_{\delta_{-i}} [R + v(\delta, \delta_{-i})] + \delta R + \delta u_\delta(\delta).
\end{aligned} \tag{46}$$

Hence, $\mathbb{E}_{\delta_{-i}} [v(\delta, \delta_{-i})] = u(\delta) - \delta u_\delta(\delta)$. Taking expectations over $\delta \sim F$ yields

$$\mathbb{E}_\delta [\mathbb{E}_{\delta_{-i}} [v(\delta, \delta_{-i})]] = \mathbb{E}_\delta [u(\delta)] - \mathbb{E}_\delta [\delta u_\delta(\delta)]. \tag{47}$$

On the other hand, we have $\mathbb{E}_\delta [\mathbb{E}_{\delta_{-i}} [v(\delta, \delta_{-i})]] = \mathbb{E}_\delta [u_\delta(\delta)]$ by (43). Hence, $\mathbb{E}_\delta [u(\delta)] = \mathbb{E}_\delta [(1 + \delta) u_\delta(\delta)]$. This completes the proof of Lemma 7(i). *Ad (ii)*: Follows from (45). *Ad (iii)*: Follows from (46). *Ad (iv)*: Follows from (43). ■

Proof of Lemma 8. Notice first that the conditions of Lemma 7(i) are invariant to a multiplication of u with a positive scalar. Let $\alpha = 1$ in the following. Obviously, $u_{\delta\delta} > 0$, and

$u(\delta) \geq 0$ for all δ . Since $u_\delta(\delta) = -2(\delta_* - \delta)$, we have $\mathbb{E}_\delta[u(\delta)] = \mathbb{E}_\delta[(1 + \delta)u_\delta(\delta)]$ if and only if $\mathbb{E}_\delta[(\delta_* - \delta)^2] = -2\mathbb{E}_\delta[(1 + \delta)(\delta_* - \delta)]$, thus, if and only if $(1 + \delta_*)^2 = \mathbb{E}_\delta[(1 + \delta)^2]$. Hence, $\mathbb{E}_\delta[u] = \mathbb{E}_\delta[(1 + \delta)u_\delta(\delta)]$ is satisfied for $\delta_* = -1 + [\mathbb{E}_\delta[(1 + \delta)^2]]^{1/2}$. Since $\text{Var}_\delta[\delta] = \mathbb{E}_\delta[\delta^2] - \mathbb{E}_\delta[\delta]^2$, we have $\delta_* = -1 + [\text{Var}_\delta[\delta] + (1 + \mathbb{E}_\delta[\delta])^2]^{1/2}$. Since $\text{Var}_\delta[\delta] > 0$ by assumption, we have $\delta_* > -1 + [(1 + \mathbb{E}_\delta[\delta])^2]^{1/2} = \mathbb{E}_\delta[\delta]$. Thus, $\mathbb{E}_\delta[u_\delta(\delta)] = 2(\mathbb{E}_\delta[\delta] - \delta_*) < 0$. ■

Proof of Proposition 9. Consider an agent i of type $\delta_i \in [\delta_{\min}, \delta_{\max}]$. For arbitrary messages m_i, m_{-i} of i and $-i$, agent i realizes individual wealth

$$\pi_i(m_i, m_{-i}, x^*, x_{-i}) = x^* - C(x^*) - \mathbb{E}_\delta[u_\delta(\delta)] + u(m_i) - m_i u_\delta(m_i) + u_\delta(m_{-i}) \quad (48)$$

if $x_i = x^*$, and $\pi_i(m_i, m_{-i}, x_i, x_{-i}) = -C(x_i)$ if $x_i \neq x^*$. Notice that the agents' effort choices are independent, such that i 's effort choice does not affect $-i$'s wealth. Hence, for α sufficiently small, we have $\pi_i(m_i, m_{-i}, x^*, x_{-i}) > 0 \geq \pi_i(m_i, m_{-i}, x_i, x_{-i})$ for all $x_i \neq x^*$ and all $m_i, m_{-i} \in [\delta_{\min}, \delta_{\max}]$. Hence, each type δ_i exerts the effort $x_i = x^*$. Agent i 's ex post utility from efforts $x_i = x_{-i} = x^*$ and messages m_i, m_{-i} is thus

$$\begin{aligned} U_i(m_i, m_{-i}) &= R - \mathbb{E}_\delta[u_\delta(\delta)] + u(m_i) - m_i u_\delta(m_i) + u_\delta(m_{-i}) \\ &\quad + \delta_i [R - \mathbb{E}_\delta[u_\delta(\delta)] + u(m_{-i}) - m_{-i} u_\delta(m_{-i}) + u_\delta(m_i)]. \end{aligned} \quad (49)$$

For any $m_{-i} \in [\delta_{\min}, \delta_{\max}]$, we have $\partial U_i(m_i, m_{-i}) / \partial m_i = (\delta_i - m_i) u_{\delta\delta}(m_i)$; thus, $m_i = \delta_i$. Hence, truthful revelation is a dominant strategy for each type $\delta_i \in [\delta_{\min}, \delta_{\max}]$. By (49), implementation of W^p with a randomly selected type $\delta_{-i} \sim F$ yields agent i of type δ_i an expected utility level of

$$\begin{aligned} \mathbb{E}_{\delta_{-i}}[U_i[\delta_i; \delta_i, \delta_{-i}, x^*, x^*]] &= \mathbb{E}_{\delta_{-i}}[\pi_i(\delta_i, \delta_{-i}, x^*, x^*)] + \delta_i \mathbb{E}_{\delta_{-i}}[\pi_{-i}(\delta_{-i}, \delta_i, x^*, x^*)] \\ &= R - \mathbb{E}_\delta[u_\delta(\delta)] + u(\delta_i) - \delta_i u_\delta(\delta_i) + \mathbb{E}_\delta[u_\delta(\delta)] \\ &\quad + \delta_i [R - \mathbb{E}_\delta[u_\delta(\delta)] + \mathbb{E}_\delta[u(\delta)] - \mathbb{E}_\delta[\delta u_\delta(\delta)] + u_\delta(\delta_i)] \\ &= (1 + \delta_i) R + u(\delta_i) + \delta_i [\mathbb{E}_\delta[u(\delta)] - \mathbb{E}_\delta[(1 + \delta)u_\delta(\delta)]] . \end{aligned} \quad (50)$$

By Lemmas 7(i) and 8, we have $\mathbb{E}_\delta[u] = \mathbb{E}_\delta[(1 + \delta)u_\delta(\delta)]$. Hence, $\mathbb{E}_{\delta_{-i}}[U_i[\delta_i; \delta_i, \delta_{-i}, x^*, x^*]] = (1 + \delta_i) R + u(\delta_i)$. Implementation of \mathbb{W}^s with types δ_i, δ_{-i} yields P an ex post profit of

$$\begin{aligned} \pi_P(\delta_i, \delta_{-i}) &= x^* - [v(\delta_i, \delta_{-i}) + x^*] + x^* - [v(\delta_{-i}, \delta_i) + x^*] \\ &= \mathbb{E}_\delta[u_\delta(\delta)] - u(\delta_i) + \delta_i u_\delta(\delta_i) - u_\delta(\delta_{-i}) \\ &\quad + \mathbb{E}_\delta[u_\delta(\delta)] - u(\delta_{-i}) + \delta_{-i} u_\delta(\delta_{-i}) - u_\delta(\delta_i) . \end{aligned} \quad (51)$$

Taking expectations over δ_i, δ_{-i} yields $\mathbb{E}_{\delta_i, \delta_{-i}} [\pi_P] = 2\mathbb{E}_\delta [\delta u_\delta (\delta)] - 2\mathbb{E}_\delta [u (\delta)]$. By Lemmas 7(i) and 8, we have $\mathbb{E}_\delta [u (\delta)] = \mathbb{E}_\delta [(1 + \delta) u_\delta (\delta)]$. Hence, $\mathbb{E}_{\delta_i, \delta_{-i}} [\pi_P] = 2 |\mathbb{E}_\delta [u_\delta (\delta)]|$, which is positive by Lemmas 7(i) and 8. ■

Proof of Proposition 10. An agent of type δ has the dominant effort strategy x^* . When ending up with a type δ_{-i} , type δ realizes a wealth of $\pi (\delta, \delta_{-i}) = R - \mathbb{E}_\delta [u_\delta (\delta)] + u (\delta) - \delta u_\delta (\delta) + u_\delta (\delta_{-i})$. Type δ 's ex post utility when ending up with type δ_{-i} is thus

$$\begin{aligned} u (\delta, \delta_{-i}) &= \pi (\delta, \delta_{-i}) + \delta \pi (\delta_{-i}, \delta) \\ &= (1 + \delta) [R - \mathbb{E}_\delta [u_\delta (\delta)]] + u (\delta) + \delta u (\delta_{-i}) + (1 - \delta \delta_{-i}) u_\delta (\delta_{-i}). \end{aligned} \quad (52)$$

Hence, $\partial u (\delta, \delta_{-i}) / \partial \delta_{-i} = (1 - \delta \delta_{-i}) u_{\delta\delta} (\delta) > 0$. With a realization δ, δ_{-i} of types, \mathbb{W}^s yields P the ex post profit given by (51). Hence, $\frac{\partial}{\partial \delta} \pi_P (\delta, \delta_{-i}) = -(1 - \delta) u_{\delta\delta} (\delta) < 0$. By Lemma 4, P makes a positive (negative) profit if agents are sufficiently spiteful (altruistic). ■

Proof of Lemma 11. *Ad (i):* By assumption, $W^p = [w^p (x_i, x_{-i}), w^p (x_{-i}, x_i)]$ incentivizes each agent to reveal his type truthfully while implementing the strictly dominant effort strategy $x (\delta)$ for each type $\delta \in [\delta_{\min}, \delta_{\max}]$. From implementation of W^p with a randomly selected type $\delta_{-i} \sim F$, an agent i of type δ_i expects utility

$$\begin{aligned} \mathbb{E}_{\delta_{-i}} [U_i [\delta_i; x (\delta_i), x (\delta_{-i})]] &= \mathbb{E}_{\delta_{-i}} [w^p (x (\delta_i), x (\delta_{-i}))] - C (x (\delta_i)) \\ &\quad + \delta_i \mathbb{E}_{\delta_{-i}} [w^p (x (\delta_{-i}), x (\delta_i)) - C (x (\delta_{-i}))]. \end{aligned} \quad (53)$$

Since $w^p (x_i, x_{-i})$ is twice partially continuously differentiable in x_i , $\mathbb{E}_{\delta_{-i}} [U_i [\delta_i; x (\delta_i), x (\delta_{-i})]]$ is twice continuously differentiable in $x_i = x (\delta_i)$; in particular, Leibniz' rule for differentiation under the integral sign is applicable. Since $w^p (x_i, x_{-i})$ provides each type $\delta_i \in [\delta_{\min}, \delta_{\max}]$ with a strictly dominant effort strategy $x_i = x (\delta_i)$, the *FOC*

$$0 = \frac{d}{dx_i} \mathbb{E}_{\delta_{-i}} [U_i [\delta_i; x (\delta_i), x (\delta_{-i})]]$$

and the *SOC*

$$0 > \frac{d^2}{dx_i^2} \mathbb{E}_{\delta_{-i}} [U_i [\delta_i; x (\delta_i), x (\delta_{-i})]]$$

must be satisfied for type δ_i at $x_i = x (\delta_i)$. Thus,

$$C_x (x (\delta_i)) = \mathbb{E}_{\delta_{-i}} [w_{11}^p (x (\delta_i), x (\delta_{-i})) + \delta_i w_{21}^p (x (\delta_{-i}), x (\delta_i))], \quad (54)$$

$$C_{xx} (x (\delta_i)) > \mathbb{E}_{\delta_{-i}} [w_{11}^p (x (\delta_i), x (\delta_{-i})) + \delta_i w_{22}^p (x (\delta_{-i}), x (\delta_i)) | \delta_i]. \quad (55)$$

By assumption, W^p is such that $x(\delta_i)$ is continuously differentiable and strictly monotone in δ_i ; that is, $\frac{dx}{d\delta_i} \neq 0$. Differentiating the *FOC* (54) with respect to δ_i yields

$$\begin{aligned} C_{xx}(x(\delta_i)) \frac{dx}{d\delta_i} &= \mathbb{E}_{\delta_{-i}} [w_2^p(x(\delta_{-i}), x(\delta_i))] \\ &+ \frac{dx}{d\delta_i} \mathbb{E}_{\delta_{-i}} [w_{11}^p(x(\delta_i), x(\delta_{-i})) + \delta_i w_{22}^p(x(\delta_{-i}), x(\delta_i))]. \end{aligned} \quad (56)$$

The *SOC* (55) implies that $\frac{dx}{d\delta_i}$ and $\mathbb{E}_{\delta_{-i}} [w_2^p(x(\delta_{-i}), x(\delta_i)) | \delta_i]$ have the same sign. By assumption, $\mathbb{E}_{\delta_{-i}} [U_i[\delta_i; x(\delta_i), x(\delta_{-i})]] = (1 + \delta_i)R + u(\delta_i)$, where $\mathbb{E}_{\delta_{-i}} [U_i[\delta_i; x(\delta_i), x(\delta_{-i})]]$ is differentiable in δ_i . Hence, also $u(\delta_i)$ is differentiable in δ_i . Differentiating (53) with respect to δ_i and evaluating at $\delta_i = \delta$ yields

$$\begin{aligned} R + u_\delta(\delta) &= \left. \frac{d}{d\delta_i} \mathbb{E}_{\delta_{-i}} [U_i[\delta_i; x(\delta_i), x(\delta_{-i})]] \right|_{\delta_i=\delta} \\ &= \underbrace{\left. \frac{d}{dx} \mathbb{E}_{\delta_{-i}} [U_i[\delta_i; x(\delta_i), x(\delta_{-i})]] \right|_{\delta_i=\delta}}_{\underline{\underline{FOC_0}}} \cdot \left. \frac{dx}{d\delta_i} \right|_{\delta_i=\delta} \\ &\quad + \mathbb{E}_{\delta_{-i}} [w^p(x(\delta_{-i}), x(\delta)) - C(x(\delta_{-i}))] \\ &= \mathbb{E}_{\delta_{-i}} [w^p(x(\delta_{-i}), x(\delta)) - C(x(\delta_{-i}))]. \end{aligned} \quad (57)$$

As $w^p(x_i, x_{-i})$ is partially differentiable in x_{-i} , Leibniz' rule implies that u_δ is differentiable in δ . Differentiating (57) with respect to δ yields

$$u_{\delta\delta}(\delta) = \mathbb{E}_{\delta_{-i}} [w_2^p(x(\delta_{-i}), x(\delta))] \cdot \left. \frac{dx}{d\delta_i} \right|_{\delta_i=\delta}. \quad (58)$$

Since $\frac{dx}{d\delta_i}$ and $\mathbb{E}_{\delta_{-i}} [w_2^p(x(\delta_{-i}), x(\delta_i))]$ have the same sign, and $\frac{dx}{d\delta_i} \neq 0$ by assumption, (58) implies $u_{\delta\delta}(\delta) > 0$. Furthermore, taking expectations over $\delta \sim F$ in (57) yields

$$\begin{aligned} R + \mathbb{E}_\delta [u_\delta(\delta)] &= \mathbb{E}_\delta [\mathbb{E}_{\delta_{-i}} [w^p(x(\delta_{-i}), x(\delta)) - C(x(\delta_{-i}))]] \\ &= \mathbb{E}_\delta [\mathbb{E}_{\delta_{-i}} [w^p(x(\delta_{-i}), x(\delta)) - x(\delta) + x(\delta) - C(x(\delta_{-i}))]] \\ &= -\frac{1}{2} \mathbb{E}_{\delta_i, \delta_{-i}} [\pi_P] + \mathbb{E}_\delta [x(\delta) - C(x(\delta))] \end{aligned} \quad (59)$$

Hence, $\frac{1}{2} \mathbb{E}_{\delta_i, \delta_{-i}} [\pi_P] = -\mathbb{E}_\delta [u_\delta(\delta)] + \mathbb{E}_\delta [x(\delta) - C(x(\delta))] - R$, where $\mathbb{E}_\delta [x(\delta) - C(x(\delta))] < R$. On the other hand, $\mathbb{E}_{\delta_i, \delta_{-i}} [\pi_P] > 0$ by assumption. Hence, $\mathbb{E}_\delta [u_\delta(\delta)] < 0$. Finally, (57)

yields

$$\begin{aligned}
(1 + \delta) R + u(\delta) &= \mathbb{E}_{\delta_{-i}} [U_i [\delta_i; x(\delta_i), x(\delta_{-i})]] \\
&= \mathbb{E}_{\delta_{-i}} [w^p(x(\delta), x(\delta_{-i})) - C(x(\delta))] \\
&\quad + \delta \mathbb{E}_{\delta_{-i}} [w^p(x(\delta_{-i}), x(\delta)) - C(x(\delta_{-i}))] \\
&= \mathbb{E}_{\delta_{-i}} [w^p(x(\delta), x(\delta_{-i})) - C(x(\delta)) | \delta] + \delta R + \delta u_\delta(\delta). \quad (60)
\end{aligned}$$

Hence, $\mathbb{E}[w^p(x(\delta_i), x(\delta_{-i})) - C(x(\delta_i))] = \mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] = R + u(\delta_i) - \delta_i u_\delta(\delta_i)$. Taking expectations over $\delta \sim F$ yields $\mathbb{E}_\delta [\mathbb{E}_{\delta_{-i}} [w^p(x(\delta_{-i}), x(\delta)) - C(x(\delta_{-i}))]] = R + \mathbb{E}_\delta [u(\delta)] - \mathbb{E}_\delta [\delta u_\delta(\delta)]$. Substituting the latter into the first line of (59) yields $\mathbb{E}_\delta [u(\delta)] = \mathbb{E}_\delta [(1 + \delta) u_\delta(\delta)]$. This completes the proof of Lemma 11(i). *Ad (ii)*: Follows from (59). *Ad (iii)*: Follows from (60). *Ad (iv)*: Follows from (57). ■

Proof of Proposition 12. Implementation of W^p yields agent i of type δ_i ex post utility of

$$\begin{aligned}
U_i(x_i, x_{-i}) &= R - \mathbb{E}_\delta [u_\delta(\delta)] + u(h(x_i)) - h(x_i) u_\delta(h(x_i)) + u_\delta(h(x_{-i})) \\
&\quad + \delta_i [R - \mathbb{E}_\delta [u_\delta(\delta)] + u(h(x_{-i})) - h(x_{-i}) u_\delta(h(x_{-i})) + u_\delta(h(x_i))]. \quad (61)
\end{aligned}$$

Agent i 's marginal utility of his individual effort is thus

$$\frac{dU_i}{dx_i} = [\delta_i - h(x_i)] h_x(x_i) u_{\delta\delta}(h(x_i)). \quad (62)$$

Since h , the inverse of the strictly monotone type-effort correspondence x , is strictly monotone, and since $u_{\delta\delta}(h) > 0$ for all $h(x_i) \in [\delta_{\min}, \delta_{\max}]$, agent i has a unique optimum effort level x_i^* , which satisfies $\delta_i - h(x_i^*) = 0$; thus, $x_i^* = h^{-1}(\delta_i) = x(\delta_i)$. Accordingly, agent $-i$ exerts the effort $x_{-i}^* = x(\delta_{-i})$. Substituting $x_i^* = x(\delta_i)$ and $h(x_i^*) = h(x(\delta_i)) = \delta_i$ into (61), and taking expectations over $\delta_{-i} \sim F$ yields

$$\begin{aligned}
\mathbb{E}_{\delta_{-i}} [U_i [\delta_i; x(\delta_i), x(\delta_{-i})]] &= (1 + \delta_i) (R - \mathbb{E}_\delta [u_\delta(\delta)]) + u(h(x(\delta_i))) \\
&\quad + (\delta_i - h(x(\delta_i))) u_\delta(h(x(\delta_i))) \\
&\quad + \mathbb{E}_{\delta_{-i}} [u_\delta(h(x(\delta_{-i}))) + \delta_i \mathbb{E}_{\delta_{-i}} [u(h(x(\delta_{-i})))] \\
&\quad - \delta_i \mathbb{E}_{\delta_{-i}} [h(x(\delta_{-i})) u_\delta(h(x(\delta_{-i})))] \\
&= (1 + \delta_i) R + u(\delta_i) + \delta_i \mathbb{E}_\delta [u(\delta)] - \delta_i \mathbb{E}_\delta [(1 + \delta) u_\delta(\delta)] \quad (63)
\end{aligned}$$

By Lemma 11(i), $\mathbb{E}_\delta [u(\delta)] = \mathbb{E}_\delta [(1 + \delta) u_\delta(\delta)]$. Thus, $\mathbb{E}_{\delta_{-i}} [U_i [\delta_i; x(\delta_i), x(\delta_{-i})]] = (1 + \delta_i) R +$

$u(\delta_i) \geq \underline{u}(\delta)$. Hence, if an agent i of any type δ believes that agent $-i$ of any type $\delta_{-i} \sim F$ will accept W^p , then agent i himself accepts W^p . Implementation of W^p with types δ, δ_{-i} yields P an ex post profit of

$$\begin{aligned} \pi_P(\delta, \delta_{-i}) &= x(\delta) + x(\delta_{-i}) - w^p(x(\delta), x(\delta_{-i})) - w^p(x(\delta_{-i}), x(\delta)) \\ &= \mathbb{E}_\delta[u_\delta(\delta)] - R + x(\delta) - C(x(\delta)) - u(\delta) - (1 - \delta)u_\delta(\delta) \\ &\quad + \mathbb{E}_\delta[u_\delta(\delta)] - R + x(\delta_{-i}) - C(x(\delta_{-i})) - u(\delta_{-i}) - (1 - \delta_{-i})u_\delta(\delta_{-i}) \end{aligned} \quad (64)$$

Taking expectations over δ, δ_{-i} and applying the identity $\mathbb{E}_\delta[u(\delta)] = \mathbb{E}_\delta[(1 + \delta)u_\delta(\delta)]$ of Lemma 11(i), which is satisfied according to Lemma 8, yields $\mathbb{E}_{\delta_i, \delta_{-i}}[\pi_P] = 2|\mathbb{E}_\delta[u_\delta(\delta)]| + 2(\mathbb{E}_\delta[x(\delta) - C(x(\delta))] - R)$, which is positive due to the assumptions on x . Unanimous approval of W^p thus constitutes a PBE. Since $\frac{d}{dy}u_\delta(h(y)) = u_{\delta\delta}(h(y))h_x(y)$ and $u_{\delta\delta} > 0$, agent $-i$'s effort x_{-i} imposes a positive (negative) externality on agent i 's pay if and only if $h_x > 0$ (< 0), thus, if and only if $\frac{dx}{d\delta} = \frac{dh^{-1}(\delta)}{d\delta} > 0$ (< 0). Finally, since $\lim_{\alpha \rightarrow 0} w^p(x, y) = R + C(x) > 0$, the agents' limited liability is met when letting $\alpha \rightarrow 0$, while P 's profit increases in α . Hence, P chooses the maximum value of α that just meets with the agents' limited liability for any composition of types. ■

Proof of Proposition 13. In the PBE with unanimous approval of the contract W^p of Proposition 12, the principal expects a profit of

$$\begin{aligned} \mathbb{E}_{\delta_i, \delta_{-i}}[\pi_P] &= 2|\mathbb{E}_\delta[u_\delta(\delta)]| + 2(\mathbb{E}_\delta[x(\delta) - C(x(\delta))] - R) \\ &= 4\alpha(\delta_* - \mathbb{E}_\delta[\delta]) + 2(\mathbb{E}_\delta[x(\delta) - C(x(\delta))] - R). \end{aligned} \quad (65)$$

Since $\text{Var}_\delta[\delta] > 0$, we have $\delta_* > \mathbb{E}_\delta[\delta]$, which allows for infinitely many type-effort correspondences x satisfying the assumption $\mathbb{E}_\delta[x(\delta) - C(x(\delta))] > R - 2\alpha(\delta_* - \mathbb{E}_\delta[\delta])$ of Proposition 12: Any strictly monotone function $x : [\delta_{\min}, \delta_{\max}] \rightarrow [\underline{x}, \bar{x}]$ satisfying $\mathbb{E}_\delta[x(\delta) - C(x(\delta))] = R - \varepsilon$ for some sufficiently small $\varepsilon > 0$ can be chosen, and for each $\varepsilon > 0$ infinitely many of such functions exist. With the gain function u being fixed, any choice of x implements the very same expected utilities for the agents. Hence, there are infinitely many, *ex interim* payoff equivalent, pooling contracts that Pareto dominate the status quo in PBE. The payoff equivalence of relative and team performance pay is immediate from Proposition 12. ■

Proof of Proposition 14. An agent of type δ has the dominant effort strategy $x(\delta)$, with $h(x(\delta)) = \delta$, and receives direct compensation for his costs of effort. According to (21), a type δ receives an ex post wealth of $\pi(\delta, \delta_{-i}) = R - \mathbb{E}_\delta[u_\delta(\delta)] + u(\delta) - \delta u_\delta(\delta) + u_\delta(\delta_{-i})$ when ending up with a type δ_{-i} . Type δ 's ex post utility $u(\delta, \delta_{-i})$ is thus the same as

under interim-efficient screening, and given by (52). Hence, $\partial u(\delta, \delta_{-i}) / \partial \delta_{-i} > 0$. With a realization δ, δ_{-i} of types, W^P yields P an ex post profit as given by (64). Hence,

$$\begin{aligned} \frac{\partial}{\partial \delta} \pi_P(\delta, \delta_{-i}) &= \frac{d}{d\delta} [x(\delta) - C(x(\delta))] - (1 - \delta) u_{\delta\delta}(\delta) \\ &= [1 - C_x(x(\delta))] \frac{dx(\delta)}{d\delta} - (1 - \delta) u_{\delta\delta}(\delta). \end{aligned} \quad (66)$$

P seeks to minimize the production inefficiency caused by distorted incentives and chooses $x : [\delta_{\min}, \delta_{\max}] \rightarrow [\underline{x}, \bar{x}]$ such that it satisfies $\mathbb{E}_\delta [x(\delta) - C(x(\delta))] = x^* - C(x^*) - \varepsilon$ for some sufficiently small $\varepsilon > 0$. Hence, for some $\varepsilon', \varepsilon'' > 0$, we have $|x(\delta) - x^*| < \varepsilon'$ and $|1 - C_x(x(\delta))| < \varepsilon''$ for almost all $\delta \in [\delta_{\min}, \delta_{\max}]$. Since $\varepsilon', \varepsilon'' \rightarrow 0$ as $\varepsilon \rightarrow 0$, and since $|x_\delta(\delta)|$ is bounded, we have $\lim_{\varepsilon \rightarrow 0} [1 - C_x(x(\delta))] dx(\delta) / d\delta = 0$. Hence, for ε sufficiently small, $\partial \pi_P(\delta, \delta_{-i}) / \partial \delta < 0$. By Lemma 4, P then makes a positive (negative) profit if agents are sufficiently spiteful (altruistic). ■

B Omitted Derivations

Derivation of Eq.(17) from Eq.(16). For an interim-efficient screening contract \mathbb{W}^s in the form of (13), with a salary component v in the form of (16), that incentivizes truthful revelation of types, the identities of Lemma 7(*iii*),(*iv*) read

$$\begin{aligned}\mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] &= R + g(\delta_i) + z(\delta_i) - \mathbb{E}_{\delta_{-i}}[z(\delta_{-i})] \\ &= R + u(\delta_i) - \delta_i u_\delta(\delta_i),\end{aligned}\tag{67}$$

$$\begin{aligned}\mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i] &= R + \mathbb{E}_{\delta_{-i}}[g(\delta_{-i})] + \mathbb{E}_{\delta_{-i}}[z(\delta_{-i})] - z(\delta_i) \\ &= R + u_\delta(\delta_i).\end{aligned}\tag{68}$$

The principal's expected profit is

$$\mathbb{E}_{\delta_i, \delta_{-i}}[\pi_P] = -2\mathbb{E}_{\delta_{-i}}[g(\delta_{-i})].\tag{69}$$

Combining (69) with Lemma 7(*ii*) yields $\mathbb{E}_{\delta_{-i}}[g(\delta_{-i})] = \mathbb{E}_{\delta_{-i}}[u_\delta(\delta_{-i})]$. Substituting the latter into (68) gives

$$z(\delta_i) = \mathbb{E}_{\delta_{-i}}[z(\delta_{-i})] + \mathbb{E}_{\delta_{-i}}[u_\delta(\delta_{-i})] - u_\delta(\delta_i).\tag{70}$$

Adding now (67) and (70) yields

$$g(\delta_i) = -\mathbb{E}_{\delta_{-i}}[u_\delta(\delta_{-i})] + u(\delta_i) + (1 - \delta_i)u_\delta(\delta_i).\tag{71}$$

Normalizing $\mathbb{E}_{\delta_{-i}}[z(\delta_{-i})] = -\mathbb{E}_{\delta_{-i}}[u_\delta(\delta_{-i})]$ in (70) gives $z(\delta_i) = -u_\delta(\delta_i)$. Hence, $v(\delta_i, \delta_{-i}) = -\mathbb{E}_\delta[u_\delta(\delta)] + u(\delta_i) - \delta_i u_\delta(\delta_i) + u_\delta(\delta_{-i})$. ■

Derivation of Eq.(21) from Eq.(20). For an interim-efficient pooling contract in the form of $w^p(x_i, x_{-i}) = v(x_i) + z(x_i) - z(x_{-i})$ implementing the type-effort correspondence $x : [\delta_{\min}, \delta_{\max}] \rightarrow [\underline{x}, \bar{x}]$ and the gain function $u : [\delta_{\min}, \delta_{\max}] \rightarrow [0, \infty)$, the identities of Lemma 11(*iii*),(*iv*) read

$$\begin{aligned}\mathbb{E}_{\delta_{-i}}[\pi_i | \delta_i] &= v(x(\delta_i)) + z(x(\delta_i)) - C(x(\delta_i)) - \mathbb{E}_{\delta_{-i}}[z(x(\delta_{-i}))] \\ &= R + u(\delta_i) - \delta_i u_\delta(\delta_i),\end{aligned}\tag{72}$$

$$\begin{aligned}\mathbb{E}_{\delta_{-i}}[\pi_{-i} | \delta_i] &= \mathbb{E}_{\delta_{-i}}[v(x(\delta_{-i}))] + \mathbb{E}_{\delta_{-i}}[z(x(\delta_{-i}))] - \mathbb{E}_{\delta_{-i}}[C(x(\delta_{-i}))] - z(x(\delta_i)) \\ &= R + u_\delta(\delta_i).\end{aligned}\tag{73}$$

The principal's expected profit simplifies to

$$\mathbb{E}_{\delta_i, \delta_{-i}} [\pi_P] = 2\mathbb{E}_{\delta_{-i}} [x(\delta_{-i})] - 2\mathbb{E}_{\delta_{-i}} [v(x(\delta_{-i}))]. \quad (74)$$

Combining (74) with Lemma 11 (ii) yields $\mathbb{E}_{\delta_{-i}} [v(x(\delta_{-i})) - C(x(\delta_{-i}))] = \mathbb{E}_{\delta_{-i}} [u_\delta(\delta_{-i})] + R$. Substituting the latter into (73) gives

$$z(x(\delta_i)) = \mathbb{E}_{\delta_{-i}} [z(x(\delta_{-i}))] + \mathbb{E}_{\delta_{-i}} [u_\delta(\delta_{-i})] - u_\delta(\delta_i). \quad (75)$$

Adding now (72) and (75) yields

$$v(x(\delta_i)) = R - \mathbb{E}_{\delta_{-i}} [u_\delta(\delta_{-i})] + C(x(\delta_i)) + u(\delta_i) + (1 - \delta_i) u_\delta(\delta_i). \quad (76)$$

Denote by $h : [\underline{x}, \bar{x}] \rightarrow [\delta_{\min}, \delta_{\max}]$ the inverse of the strictly monotone type-effort correspondence $x : [\delta_{\min}, \delta_{\max}] \rightarrow [\underline{x}, \bar{x}]$; that is, $\delta = h(x(\delta)) = h(x)$ for any $\delta \in [\delta_{\min}, \delta_{\max}]$. Substituting $\delta = h(x)$ into (75) and (76), and normalizing $\mathbb{E}_{\delta_{-i}} [z(x(\delta_{-i}))] = -\mathbb{E}_{\delta_{-i}} [u_\delta(\delta_{-i})]$ in (75), gives

$$v(x) = R - \mathbb{E}_\delta [u_\delta(\delta)] + C(x) + [1 - h(x)] u_\delta(h(x)) + u(h(x)), \quad (77)$$

$$z(x) = -u_\delta(h(x)). \quad (78)$$

Hence, $w^p(x_i, x_{-i}) = R - \mathbb{E}_\delta [u_\delta(\delta)] + C(x_i) + u(h(x_i)) - h(x_i) u_\delta(h(x_i)) + u_\delta(h(x_{-i}))$. ■