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OPTIMAL CONTRACTS WHEN AGENTS ENVY EACH OTHER

by

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ABSTRACT

We examine the characteristics of endogenously-determined optimal incentive contracts for agents who envy each other and work for a risk-neutral (non-envious) principal. Envy makes each agent care not only about absolute consumption but also about relative consumption. Incentive contracts in this setting display properties strikingly different from those associated with optimal contracts in standard principal-agent theory. We derive results that help explain some of the discrepancies between the predictions of principal-agent theory and the stylized facts about real-world contracts. We also show how seemingly envious behavior can emerge with asymmetric information even when envy is *not* biologically hard-wired into agents' preferences.

OPTIMAL CONTRACTS WHEN AGENTS ENVY EACH OTHER

"Oh, what a bitter thing it is to look into happiness through another man's eyes." William Shakespeare

1. INTRODUCTION

Principal-agent theory has derived optimal compensation contracts in various circumstances (see Prendergast (1999)). The basic assumptions in this literature are that the agent is risk averse, effort-averse, and has utility over consumption that is dependent only on his own wage and is increasing in this wage. The last assumption is at odds with the emerging literature on envy and interdependent preferences (e.g., Akerlof and Yellen (1990), Bolton and Ockenfels (2000), Charness and Rabin (2002), and Fehr and Schmidt (1999)), which asserts that an individual cares not only about his own absolute consumption but also about how his consumption compares with that of a reference group. The inclusion of envy in an individual's preferences means that the individual gains utility when his consumption exceeds his reference group's, and loses utility when his consumption falls below the reference group's. While such preferences have numerous potential applications,[1] an especially interesting one is when a team of agents reports to a principal, since the team represents a natural reference group for each agent. In particular, what are the characteristics of optimal incentive contracts when there is envy among multiple agents reporting to the same principal? In addressing this question, we derive results that help explain documented gaps between real-world contracts and the predictions of standard principal-agent theory.

The justification for including envy in agents' preferences comes from four perspectives: biology, psychology, sociology, and economics. Robson (2001) explains that the biological foundations of envy arise from the evolutionary hard-wiring of envy into preferences because it facilitates reproductive success. Adams (1963) proposes a psychological theory of inequity in which people compare their own reward (wages) - input (effort) ratios with those of others and adjust their inputs to achieve equity of ratios. The sociological implications of envy are discussed by Elster (1991), who argues that we are more envious of those who are more similar to us, reminiscent of Aristotle (*Rhetoric*, 1388a): "We envy those who are near us in time, place, age, or reputation." Salovey and Rodin (1984) provide evidence of this.

[1] We discuss this literature in greater detail later.

The economics justification for envy has experimental (Martin (1981), Zizzo and Oswald (2001), Cason and Mui (2002), and Grolleau, Mzoughi, and Sutan (2006)) as well as empirical bases (Frank (1984), Pfeffer and Davis-Black (1992), Pfeffer and Langton (1993), and Luttmer (2004)).

For our analysis, we apply the insights of the literature on envy to a principal-agent setting in which multiple agents are endowed with concave utility functions increasing in their own wages and decreasing in the wages of other agents. Empirical evidence supports this kind of specification. For example, in a survey of college and university faculty, Pfeffer and Langton (1993) find that wage dispersion adversely affects faculty members' self-reported satisfaction, productivity, and research collaboration.[2] Our specification also finds support in the theoretical and experimental literature on inequality aversion. This literature considers "social" or "interdependent" preferences and takes the view that people are motivated by considerations of fairness and wish to reduce inequality. This has led to the adoption of preferences such that agents dislike inequality but their dislike for inequality is greater when they are worse off than others than when they are better off than others (see Fehr and Schmidt (1999)).[3]

Our approach generates numerous results. First, the wage of an agent may depend on the performance indicators of other agents even when these indicators provide no information about his action choice. This may explain empirically-documented violations of Holmstrom's (1979) "informativeness principle" -- derived in a no-envy setting -- which states that an agent's compensation must depend *only* on those outcomes that provide incremental information about his action choice.

Second, an agent's wage is *increasing* in the outcome of every other agent, so optimal contracts are consistent with real-world contracts that pay individuals both for team performance and individual performance. But this result is in striking contrast to the relative-performance-evaluation literature where an agent's wage is *decreasing* in the outcomes of other agents (e.g., Lazear and Rosen (1981)). Moreover, our result may also explain the prevalence of equity-based compensation whereby workers invest in the

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[2] Frey and Stutzer (2002) review the literature on happiness and relative positions. Layard (2003) provides a summary of the happiness research. Luttmer (2004) provides recent evidence of envy among neighbors.

[3] One difference between the utility specification in this literature and in our paper is that this literature assumes a symmetry in preferences as manifested in an individual's dislike for being both better off and worse off than others, whereas we assume a dislike only for being worse off. This difference will be discussed further in Section 2.

shares of their own firms despite an increase in their undiversified exposure to idiosyncratic risk.

Third, in our analysis the envy experienced by an agent depends on the agent's reference group, which the principal can affect, so we ask: is envy among agents good or bad for the principal? We show that envy has two opposing effects on the principal's expected payoff. On the one hand, envy makes it easier to provide agents incentives to work hard ("incentive effect"). That is, envy helps mitigate the problem of it being too hard to motivate agents who are "too rich." On the other hand, envy reduces the expected utility of the agents, *ceteris paribus*, and the principal has to compensate for this with higher wages ("direct utility effect"). The overall effect of envy depends on which effect dominates, and we derive conditions under which envy among agents makes the principal better off as well as those under which it makes the principal worse off. Moreover, increasing the number of envious agents in the team can make the principal worse off, so that the relationship between group size and performance may be driven by the tradeoff between envy and complementarities among agents. This may explain the documented negative relationship between profitability and the number of employees (e.g., Kaen and Baumann (2003)).

Fourth, envious agents benefit from colluding not to compete, which provides a different perspective on the cooperation-versus-competition choice from that in the literature (e.g., Itoh (1991)).

Fifth, the pay-for-performance sensitivity of linear wages is lower when agents are envious, consistent with the evidence that executive compensation exhibits lower-than-predicted pay-for-performance sensitivity (e.g., Jensen and Murphy (1990)). Our results also rationalize the empirically-documented wage (or ratings) compression in firms (e.g., Prendergast (1999) and Landy and Farr (1980)). Moreover, if envy plays a greater role in larger firms, then our analysis implies pay-for-performance sensitivity should be higher in smaller firms, consistent with the evidence (e.g., Rasmusen and Zenger (1990)).

Sixth, we show that agents can be divided into mutually exclusive groups such that an agent's wage depends on the outcomes of all other agents in his group, but *not* on the outcomes of agents in *other* groups. This suggests a correlation between wages and one's level in the hierarchy.

Finally, we show that with even standard (non-envy) preferences, behavioral outcomes with informational frictions and private benefits can mimic those attained with envy-based preferences. Thus, our results may extend even to circumstances where envy is *not* biologically hard-wired.

This paper contributes to the literature on principal-agent theory and on envy. The principal-agent theory literature is too large to discuss here; see Prendergast's (1999) review as well as Gibbons (1998), Gibbons and Waldman (1999), Lazear (1995), and Murphy (1999). The key results are the following. First, agents respond positively to performance incentives built into their compensation. Second, the tradeoff between risk sharing and incentives means that contracts are less performance-sensitive when outcome risk is greater. Third, the informativeness principle precludes dependence of an agent's compensation on noisy variables that convey no *incremental* information about the agent's action.

The empirical evidence on these results is mixed. First, while agents do respond to incentives, real-world contracts do not seem to be as performance-sensitive as the theory predicts (see, for example, Jensen and Murphy (1990) and Milbourn (2003)). Second, the relationship between risk and incentives appears to be sometimes tenuous in practice (see Prendergast (2002)). Third, and most significantly, the informativeness principle appears to often be violated. For example, team-production-based compensation or profit-sharing plans are widely used even when measures of individual performance are available (see Baker, Jensen, and Murphy (1988), Hansen (1997), Jones and Kato (1995), and Weiss (1987)).[4]

Our contribution to this literature is to show that the introduction of envy into preferences helps narrow the gap between the theory and observed characteristics of real-world contracts. We show that an increase in envy may cause a reduction in the sensitivity of an agent's compensation to his own performance. Moreover, we explain that envy can rationalize the use of measures of aggregate performance for individual compensation even when measures of individual performance are available.

The theoretical envy literature has examined the behavioral implications of envy-based preferences. For example, Bolton and Ockenfels (2000), Charness and Rabin (2002), and Fehr and

[4] Prendergast (1999; p. 21) notes in his survey, "Perhaps the most striking aspect of observed contracts is that the Informativeness Principle, ... , seems to be violated in many occupations."

Schmidt (1999) explain why individuals display self-interested behavior in some experiments and equity-motivated behavior in others.[5] Envy-based preferences have also been used to explain emulative activity (Clark and Oswald (1996)), involuntary unemployment (Akerlof and Yellen (1990)), progressive taxation (Banerjee (1990)), wage compression (Frank (1984), Lazear (1989), and Levine (1991)), suboptimal innovation (Mui (1995)), and corporate socialism in investment decisions (Goel and Thakor (2005)).

These papers have recognized the relationship between the observed deviations from self-interest and the institutional environment in which individuals display such behavior, but they do not examine the optimal institutional design in light of such behavior. Cabrales and Charness (2003) and Fehr, Klein, and Schmidt (forthcoming) show experimentally that social preferences affect contract choice in adverse-selection and moral hazard settings. However, Fehr and Schmidt (2002) point out that the literature has ignored the effects of social or interdependent preferences in optimal incentive contract design. Since then, numerous papers have advanced this literature in various ways. But none characterizes optimal incentive contracts with moral hazard and risk aversion with envious agents.[6]

Dur and Glazer (forthcoming) and Englmaier and Wambach (2005) focus on a single agent who envies the principal, while we consider multiple agents who work for the same principal and envy *each other*.[7] Bartling and von Siemens (2006), in a setting similar to ours, consider moral hazard with envious

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[5] Such behavior is consonant with preferences that depend on absolute as well as relative consumption (Bolton and Ockenfels (2000)). Individual utility is maximized at a finite threshold level of relative consumption and people may exhibit self interest or equity concerns depending on how their relative consumption compares with the threshold. Similarly, Fehr and Schmidt (1999) specify preferences that depend on absolute consumption as well as relative consumption to rationalize self-interested and inequality-avoiding behavior in different experiments under the assumption that there is a fraction of individuals who are inequality-averse.

[6] Demougin and Fluet (2003), Demougin, Fluet, and Helm (2006), Grund and Sliwka (2005), Itoh (2004), Neilson and Stowe (2005) all model risk-neutral agents and therefore do not consider the tradeoff between risk and incentive provision. Demougin and Fluet (2003) and Grund and Sliwka (2005) focus on tournaments where only the rank order of agents' outcomes is used to reward them. Rey Biel (2005) considers deterministic production with observable effort so agents' wages do not depend on noisy outcomes. Demougin and Fluet (2003), Demougin, Fluet, and Helm (2006), and Rey Biel (2005) also assume agents have limited liability. Neilson and Stowe (2005) study optimal piece-rate by restricting each agent's wage to be a linear function of her output.

[7] Englmaier and Wambach (2005) extend their model to discuss two agents who are averse to inequity in wages. They state that there is a rationale for team incentives, but do not prove so. They claim that the wage of an agent may be decreasing in the outcome of another agent when the first agent is already far better off than the second. However, by solving for optimal wage contracts with multiple agents, we show that the wage of an agent is always increasing in the outcomes of other agents. Further, Englmaier and Wambach do *not* discuss the pay-for-performance sensitivity of wage contracts that we examine.

risk-averse agents. They show that envy allows the principal to overcome limited liability constraints and impose stronger punishments on agents. We do *not* assume limited liability. While we characterize optimal contracts, Bartling and von Siemens focus on whether envy among agents makes the principal better or worse off. We also discuss this interesting question but realize that such analyses are incomplete in the absence of additional structure related to the external opportunities of agents.

Many of these papers assume specific functional forms for how an agent's utility depends on other agents' outcomes. Our preference specification is general enough to have these specifications as special cases. The common theme in this literature is that social preferences affect incentives, optimal contracts, production efficiency, and the principal's payoffs, and can strengthen or weaken the incentive effects of performance-sensitive wage contracts; we do show, however, that the presence of social preferences strengthens incentive effects. We characterize optimal contracts under a general social preference specification, and examine when such preferences make the principal better or worse off.

In a related paper, Meyer and Mookherjee (1987) examine how agents' wage contracts are designed by a social planner with a preference for ex-post wage equality. They show that with outputs uncorrelated across agents, wage contracts based on output rank-ordering are dominated by independent contracts, and that wages are optimally positively correlated. We derive these and other results with a principal who maximizes profits net of agents' wages. Our results provide a rationale for why *capitalist firms*, where the principal maximizes profits rather than social welfare, may surprisingly exhibit behavior that reeks of equity promotion among agents. That is, some common properties of contracts in our analysis and in Meyer and Mookherjee (1987) raise the possibility that the social preferences of individuals over contracts can be reduced to having a principal with preferences that *aggregate* agents' social preferences.[8]

As our analysis shows, one reason for this is that even a profit-maximizing principal must respect the incentive compatibility and participation constraints of agents, and this causes the principal to design

[8] However, this result seems difficult to prove in a general setting in view of the impossibility theorems about aggregation of individual preferences into social choice functions. See Arrow (1963) and Sen (1970a, 1970b).

contracts recognizing both the positive incentive and negative direct utility effects of envy, which naturally leads to wages being positively correlated across agents even when the principal has no ex-post equality preference. Thus, a model like Meyer and Mookherjee (1987), that starts with such a preference, could be viewed as reflecting in reduced form more primitive considerations of envy among agents.

The rest is organized as follows. Section 2 describes the model. Section 3 characterizes optimal contracts for a single principal and multiple envious agents. Section 4 analyzes how envy affects agents' action choices and the principal's expected payoff. Section 5 examines how envy affects pay-performance sensitivity in wage contracts. Section 6 discusses that our results are robust to alternative preferences based on relative payoffs. Section 7 shows theoretically how envy like behavior can arise as a result of informational frictions. Section 8 concludes. All proofs are in the Appendix.

2. MODEL

There is a team of n ex ante identical agents, indexed, 1 through n, and there is a single principal. Let $N \equiv \{1, \ldots, n\}$. Agent $i \in N$ chooses a privately-observed action $a_i \in \Re$, where $\Re$ is the real line. There are n outcomes, $(x_1, \ldots, x_n) \in \Re^n$, observed by the principal as well as the agents. The sets of actions and outcomes are represented by $A \equiv (a_1, \ldots, a_n)$ and $X \equiv (x_1, \ldots, x_n)$. The probability density of the outcomes depends on the agents' actions and is given by $g(X, A)$. For simplicity, we assume that outcome x_j is associated with agent j and is distributed independently of a_i if $i \neq j$. Further, all outcomes are independently distributed. That is, $g(X, A) = \prod_{i \in N} g(x_i, a_i)$.

The n outcomes determine the total payoff to be shared between the principal and the agents. This total payoff equals $f(X)$, a symmetric function of the n outcomes. That is, $f(\hat{x}_1, \hat{x}_2, \ldots, \hat{x}_n) = f(\bar{x}_1, \bar{x}_2, \ldots, \bar{x}_n)$ if $(\bar{x}_1, \bar{x}_2, \ldots, \bar{x}_n)$ is a permutation of $(\hat{x}_1, \hat{x}_2, \ldots, \hat{x}_n)$. Since all agents are ex ante identical, the total payoff depends only on the realized outcomes and not on the identity of the agents associated with individual outcomes. The principal specifies the wage functions of agents that determine the payoffs to respective agents based on the outcomes. The wages are denoted as $W \equiv (w_1, \ldots,$

w_n). The principal is risk neutral and wants to maximize his expected payoff net of agents' wages.

Some examples of such teams of agents are divisional heads in a conglomerate, product managers in a multiproduct firm, a team of salespersons, members of consulting firms, and project managers in a software firm. In all these cases, multiple agents take individual actions and their individual performances can be (noisily) observed, with performance complementarities across agents that would explain why agents work in teams rather than independently. Although our key results do not depend on such complementarities, they can be incorporated by assuming that the principal's benefit function f is supermodular in agents' outcomes. Supermodularity of the total payoff requires:

$$\begin{aligned} & f(\hat{x}_1, \hat{x}_2, \ldots, \hat{x}_n) + f(\bar{x}_1, \bar{x}_2, \ldots, \bar{x}_n) \\ & \quad \leq f(\hat{x}_1 \vee \bar{x}_1, \hat{x}_2 \vee \bar{x}_2, \ldots, \hat{x}_n \vee \bar{x}_n) + f(\hat{x}_1 \wedge \bar{x}_1, \hat{x}_2 \wedge \bar{x}_2, \ldots, \hat{x}_n \wedge \bar{x}_n) \end{aligned}$$

where $(\hat{x}_1, \hat{x}_2, \ldots, \hat{x}_n)$ and $(\bar{x}_1, \bar{x}_2, \ldots, \bar{x}_n)$ are arbitrary vectors, $\vee$ is the maximum operator and $\wedge$ is the minimum operator. It can be shown that with such a specification, a high outcome by one agent increases the marginal benefit of another agent's outcome to the principal. These outcome complementarities distinguish a team of agents from multiple agents working independently for the same principal.

The agents are risk averse and envy each other. The preferences of an agent are represented by the utility function $U : \Re^n \times \Re \rightarrow \Re$, which is expressed as follows for agent i:

$$U_i(W, a_i) = v(w_i) + \gamma \sum_{j \in N - \{i\}} \phi(w_i - w_j) + \xi(\gamma) - c(a_i). \tag{1}$$

The function v depends only on the agent's own wage w_i, and is twice continuously differentiable with $v' > 0$, $v'' < 0$. The function ϕ captures the agent's utility over relative wages.[9] It is twice continuously differentiable, and is normalized so that $\phi(0) = 0$; we will refer to ϕ as the "envy function."[10]

[9] We assume envy depends on difference of wages. While more general specifications are possible, almost all papers in this area agree on difference of wages as the source of envy. It is unlikely that a different specification will change our results qualitatively.

[10] The envy function depends on a comparison of wages, rather than action-adjusted wages. The rationale for this is that agents make their action choices optimally and compare their ex-post realized wages. The alternative specification in which agents compare action-adjusted wages would imply that agents would not be as averse to the high wage realizations of other agents if they believed that these other agents worked harder. This is based on a

The constant $\gamma > 0$ measures how envious the agent is, with higher γ designating more envy. The constant $\xi(\gamma)$ does not affect an agent's preferences over wages but allows agents with different γ's to have different expected utilities even in the absence of relative wage differences. Since we do not restrict the functional form of $\xi(\gamma)$, this specification is general enough to permit the agent's expected utility to increase or decrease due to $\xi(\gamma)$ as γ increases. Finally, $c(a_i)$, the disutility associated with action a_i, is convex and twice continuously differentiable, with $c'(a) \leq 0$ for $a \leq \underline{a}$ and $c'(a) > 0$ for $a > \underline{a}$, where $\underline{a} \in \Re$. Thus, each agent experiences positive marginal utility from action below a threshold $\underline{a}$. However, this feature is unnecessary for our results, and $\underline{a}$ may be $-\infty$. Each agent chooses an action to maximize his expected utility, assuming every other agent maximizes his utility. Each agent's reservation utility, $U^*(\gamma)$, depends on γ because an agent's outside opportunities may be affected by it.

The literature suggests two aspects of envy. First, individuals dislike payoffs lower than those of others and second, they like payoffs higher than those of others.[11] While the first aspect has unanimous agreement in the literature on relative-consumption preferences, there are alternative specifications for the second aspect. For example, in the inequality-aversion literature individuals dislike either being better or worse off than others (e.g., Bolton and Ockenfels (2000)), whereas in the envy literature individuals always like being better off than others (e.g., Mui (1995)).[12] The experimental evidence is mixed. In some cases, individuals simply dislike *any* form of inequality, whereas in others they behave selfishly, displaying an aversion only to being worse off than others.[13] For example, Zizzo and Oswald's (2001) experiments suggest that people may be willing to *pay* to reduce the incomes of even those who are worse off than them. Similarly, Cason and Mui (2002) present experimental evidence that innovations that are

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fairness motive for envy. In our model, all agents are ex-ante identical, make identical action choices, and get the same wage contracts, so fairness is not an issue.

[11] For simplicity, we assume that each agent's payoff consists of his wages only. In general, the preferences are a function of multiple consumption goods or attributes of payoffs, and envy may then be stronger for certain attributes than for others (see Solnick and Hemenway (1998)).

[12] Later we discuss how our results would be affected if we had inequality-aversion instead of envy.

[13] The behavior of individuals also seems to depend on how they expect others to behave towards them. See Charness and Rabin (2002).

potentially Pareto improving are often avoided if these innovations benefit some people more than they do others.[14] Thus, the evidence indicates that individuals either display purely envious behavior, or even when they care about fairness, their disutility from being worse off than others exceeds that from being better off than others. This suggests a concave envy function ϕ, asymmetric around zero.

To be consistent with the envy literature, ϕ must be increasing and concave. However, to show that many of our results generalize to a *broader* set of preferences, we use a more general specification: an increase in an agent's wage increases his utility when the wages of some of the other agents are increased by the same amount while the wages of the remaining agents are left unchanged. Thus,

$$v'(w_i) + \gamma \sum_{j \in S} \phi'(w_i - w_j) > 0 \qquad \forall i \in N, S \subseteq N - \{i\} \tag{2}$$

The motivation is that even if fairness causes the marginal utility from relative wages to be negative, a higher absolute wage must increase the agent's total utility regardless of his reference group for comparison. This is trivially true when the envy function ϕ is increasing, as assumed in the envy literature. However, this may also hold if an agent's marginal utility from relative wages is negative but this effect is dominated by the positive marginal utility from absolute wages. Some of our results require that ϕ be strictly increasing, and we shall note this in context. We also assume:

$$\phi''(x) + \phi''(-x) < 0 \qquad \forall x . \tag{3}$$

This condition ensures that the *aggregate* envy-related utility from comparison across two agents is zero when the agents have the same wages, negative when their wages differ, and falls at an increasing rate as wage dispersion increases. This means that the envy-related utility reduction when one is worse off than others is larger than the utility increase, if any, when one is better off than others. The condition

[14] Blanchflower and Oswald (2000) find that a unit increase in the average income in a U.S. state decreases a resident's self-reported happiness by about as much as the increase in happiness due to a one-third unit increase in the resident's own income. Clark and Oswald (1996) find a similar but stronger relationship in Britain. In a questionnaire administered to Harvard graduate students in public health, a majority of the students responded that they would choose a world in which they earned $50,000 and others earned $25,000 over a world in which they earned $100,000 and others earned $250,000 (see Solnick and Hemenway (1998)).

clearly holds when ϕ is concave, as in Fehr and Schmidt (1999)[15]. But it may also hold if ϕ is convex in the region of positive relative wages. We prove most of our results with the most general specifications (1), (2), and (3) and will clarify if a result requires a more restrictive assumption like an increasing ϕ.

The principal's problem is to choose agents' actions A and wage contracts $W : \Re^n \to \Re^n$ to maximize her expected net payoff:

$$\int \left\{ f(X) - \sum_{i \in N} w_i(X) \right\} g(X, A) dX \tag{4}$$

subject to the agents' individual rationality (IR) constraints

$$\int U_i(W, a_i) g(X, A) dX \geq U^* \quad \forall i \in N \tag{5}$$

and the agents' incentive compatibility (IC) constraints

$$\begin{aligned} &\int U_i(W(X), a_i) g(X, A) dX \geq \\ &\quad \int U_i(W(X), a_i') g(X, (a_1, \ldots, a_{i-1,} a_i', a_{i+1}, \ldots, a_n)) dX \quad \forall i \in N, a_i' \in \quad \Re . \end{aligned} \tag{6}$$

A standard solution technique divides this problem into the choice of wage contracts that implement a set of actions with the lowest expected wages to the agents, and the choice of actions that maximize the risk-neutral principal's objective with the corresponding optimal wage contracts. In the subsequent analysis, we consider a principal who wants to implement actions A, and investigate how envy affects the optimal wage contracts to implement these actions. Thus, the principal's problem is:

$$\underset{W(X)}{\text{Minimize}}\, Z \equiv \int \left\{ \sum_{i \in N} w_i(X) \right\} g(X, A) dX \tag{7}$$

subject to constraints (5) and (6).

Assumption 1: The principal wants agents to implement actions strictly greater than the least-cost actions to the agents. That is, $a_i > \underline{a}\ \forall i \in N$.

[15] See Clark and Oswald (1998) for a discussion of what they call "comparison-concave" utility functions.

Assumption 1 ensures that agents must be provided incentives to implement the desired action choices. Actions least costly to the agents can be trivially implemented with fixed-wage contracts.

We employ the first-order approach and replace (6) with the following first-order conditions[16] :

$$\partial\left\{\int U_i(W(X), a_i) g(X, A) dX\right\} / \partial a_i = 0 \quad \forall i \in N . \tag{8}$$

Thus, we replace the unrelaxed problem, (5)-(7), with the relaxed problem, (5), (7), and (8). We show later that a solution to the relaxed problem is also a solution to the unrelaxed problem.

Assumption 2: There exists a solution to the principal's relaxed problem represented by (5), (7), and (8).

We further make the following assumption to ensure monotonic wage functions.

Assumption 3: The distribution functions of outcomes follow the monotone likelihood ratio property (MLRP). That is, $\frac{dg(x_i, a_i)/da_i}{g(x_i, a_i)}$ is increasing in x_i.

3. OPTIMAL CONTRACTS

We now investigate optimal wage contracts that minimize expected wages in (7) subject to the IR constraints (5) and the IC constraints (8). Choosing the Lagrange multipliers $\alpha_i \geq 0$ for (5) and β_i for (8), the Kuhn-Tucker conditions can be expressed as follows:

$$\begin{aligned} &-g(X,A)+\left[\alpha_i\left\{v'(w_i)+\gamma \sum_{j\in N-\{i\}}\phi'(w_i-w_j)\right\}-\gamma \sum_{j\in N-\{i\}}\alpha_j\phi'(w_j-w_i)\right]g(X,A) \\ &+\left[\beta_i\left\{v'(w_i)+\gamma \sum_{j\in N-\{i\}}\phi'(w_i-w_j)\right\}-\gamma \sum_{j\in N-\{i\}}\beta_j\phi'(w_j-w_i)\right]\frac{dg(X,A)}{da_i}=0 \quad \forall i \in N . \end{aligned} \tag{9}$$

The left-hand-side of (9) consists of three components representing the three marginal effects of an increase in agent i's wage on the principal's objective function: (i) $C_1 \equiv -g(X,A)$ is the change in the principal's expected payoff, (ii) $C_2 \equiv \left[\alpha_i\left\{v'(w_i)+\gamma\sum\phi'(w_i-w_j)\right\}-\gamma\sum\alpha_j\phi'(w_j-w_i)\right]g(X,A)$ is the

[16] See Rogerson (1985a) and Jewitt (1988) for the class of utility functions and production functions under which the first-order approach is valid when agents do not envy each other. The conditions specified in Rogerson (1985a) are assumed to be satisfied here.

shadow-price effect of increasing agent i's utility and decreasing other agents' envy-related utilities, and (iii) $C_3 \equiv \left[\beta_i \left\{v'(w_i) + \gamma \sum \phi'(w_i - w_j)\right\} - \gamma \sum \beta_j \phi'(w_j - w_i)\right] dg(X, A)/da_i$ is the shadow-price effect of strengthening agent i's incentive and weakening other agents' incentives.

Since the agents are ex ante identical, we can exploit symmetry to restrict $\alpha_i = \alpha$ and $\beta_i = \beta$ $\forall$ i. Further, with independent individual outcomes, the above equations simplify to

$$\frac{1}{v'(w_i) + \gamma \sum_{j \in N - \{i\}} \left\{\phi'(w_i - w_j) - \phi'(w_j - w_i)\right\}} = \alpha + \beta \frac{dg(x_i, a_i)/da_i}{g(x_i, a_i)} \quad \forall i \in N. \tag{10}$$

Lemma 1: *The Lagrange multiplier β in (10) is strictly positive.*

The intuition is as follows. If $\beta < 0$, the marginal utility of each agent is increasing in his own outcome as well as the outcome of the other agents. If $\beta = 0$, the marginal utility of an agent does not depend on his or the other agents' outcomes. In either case, the wage of an agent is non-increasing in his outcome. This, coupled with the agent's disutility for action, causes each agent to lower his action choice, which means the contracts cannot implement any action higher than $\underline{a}$. Thus, $\beta > 0$. This means that the principal's expected payoff, net of agents' wages, increases if an agent chooses an action slightly higher than his incentive-compatible action choice under the optimal wage contract.

Proposition 1: *The wage of an agent is increasing in his own outcome regardless of whether the agents envy each other. Only when the agents envy each other, the wage of each agent is also increasing in the outcome of every other agent even when the outcomes are independent.*

When agents do not envy each other, Proposition 1 shows that the wage of each agent is increasing in his outcome but is independent of the outcomes of the other agents. This familiar result from standard principal-agent theory, also noted by Green and Stokey (1983) for the case of a single principal and multiple agents in the absence of a common shock, is consistent with Holmstrom's (1979) informativeness principle. It is inefficient to base an agent's compensation on any other agent's outcome because other agents' outcomes are noisy and convey no information about the particular agent's action.

And each agent's wage is increasing in his own outcome because a higher outcome indicates a higher action choice, given the MLRP. This result provides the benchmark for our analysis with envy.

Proposition 1 says that agents' wages are increasing in their own outcomes even when agents envy each other. However, the proposition further asserts that an agent's wage is also increasing in the (independent) outcomes of other agents, and that this holds *only* when there is envy. That is, the optimal contract with envy makes an agent's compensation depend on a noisy outcome that conveys no information about the agent's action, in contrast to the informativeness principle of Holmstrom (1979) for the no-envy case.[17] The intuition is as follows. In the no-envy case of the standard principal-agent model, it is inefficient to make an agent's compensation depend on a non-informative noisy outcome because that imposes risk on the risk-averse agent without any incentive effect on his action; since the outcome conveys no information about the agent's action, he cannot affect it by choosing a higher action. All of this is true with envy as well. Basing an agent's compensation on the outcomes associated with other agents imposes risk on him without revealing any information about his action. However, if agent i's compensation is independent of agent j's outcome, when agent j experiences a higher outcome than agent i, outcome disparity results in wage disparity and envy causes this wage disparity to diminish agent i's utility. This utility reduction is a cost absorbed by the principal in meeting agent i's reservation utility. To lower this cost, the principal increases agent i's compensation when agent j's outcome is higher.[18]

The wage scheme in Proposition 1 can be interpreted as one in which a part of an agent's wage depends on his outcome and the rest depends on team performance, and offers an explanation for this observed property of real-world contracts in apparent violation of the informativeness principle (see Prendergast (1999)). As indicated earlier, individual pay is often based on the group's performance even

[17] We interpret the informativeness principle only to refer to the optimality of conditioning contracts on any signal that conveys information about an agent's action choice and the inefficiency of conditioning on non-informative noisy signals, as in Holmstrom (1979).

[18] Note that in the absence of random shocks to outputs, all agents produce the same output and get the same wage, so there is no ex-post envy. Ex-ante envy, however, affects agents' action choices and optimal wage contracts. Further, if agents are not ex-ante identical, there may be ex-post envy.

when more informative measures of individual performance are available.[19] Professional sports players, such as those in the National Football League, are paid bonuses for exceeding individual performance targets and additional bonuses for the team reaching the playoffs or winning the Super Bowl.[20]

Proposition 1 stands in contrast to the relative-performance-evaluation literature. A result in that literature is that agent's *i*'s compensation is decreasing in the outcomes of other agents (when outcomes are affected by a common shock) since higher outcomes for other agents decrease agent *i*'s performance rank (e.g., Carmichael (1983), Lazear and Rosen (1981), and Bhattacharya and Guasch (1988)).[21] The empirical evidence on relative performance evaluation is weak. Gibbons and Murphy (1990) find that executives are penalized when their peer group performs better, but this peer group is the entire stock market rather than firms in the same industry. Other studies find little evidence of relative performance evaluation (e.g., Aggarwal and Samwick (1999) and Baker, Jensen, and Murphy (1988)).[22]

An interesting question is whether Proposition 1 will hold if agents care about the outcomes of other agents for reasons *other than* envy. For example, an agent's relative outcome may be a better signal of his ability than his absolute outcome. In this case, a principal rewarding agents for their abilities will lower an agent's wage when another agent produces higher outcomes. This relative performance evaluation result -- for which we are not aware of empirical support -- is the opposite of Proposition 1.

Meyer and Mookherjee (1987) show that agents' wages are positively correlated when agents are non-envious and the principal minimizes cost subject to achieving a target level of welfare, where the

[19] Another characteristic of real-life compensation contracts is that executives are typically paid on the basis of how their firms' stock prices behave, with little or no adjustment for market movements. This result does not immediately follow from Proposition 1, but would obtain if the model were extended to incorporate envy between agents and the principal (shareholders).

[20] An alternative explanation for paying agents based on group performance is based on peer pressure, the idea that agents can monitor each other's actions and can discourage others from exerting low effort (See Kandel and Lazear (1992)). However, as mentioned by Prendergast (1999), since an agent's benefit from an increase in group performance is typically small, agents will effectively monitor and punish those exerting less effort only if the cost of doing so is negligible. Another explanation relies on production externalities. However, this approach *cannot* readily explain wage compression -- which we explain later -- in settings where individual performance matters greatly and is both observable and contractible.

[21] If we were to consider a tournament setting with a common shock, our analysis suggests that envy will alter optimal relative-performance-evaluation contracts in such a way as to (partially) blunt the incentive effect of the tournament itself. This conjecture awaits formal verification.

[22] We model agents within a firm but our results can be extended to multiple organizations in which the agents are CEOs who envy each other.

welfare function exhibits complementarities in agents' ex post wages. Thus, the principal's concern for wage equality rather than agents' envy generates positively correlated wages. The similarity and differences between that approach and ours can be understood by examining the first-order condition for wages in (9). Consider C_2 in (9), which represents the net reduction in the aggregate utility of agents from an increase in wage inequality. In Meyer and Mookherjee (1987), this component is a part of the principal's welfare function instead of entering the optimization through the agents' preferences, but it produces the same result of positively-correlated wages. What is clearly different about our model is C_3, the shadow-price effect of strengthening agent i's incentives, which is absent in Meyer and Mookhejee (1987). C_3 shows that envy among agents has incentive effects, and it strengthens agents' incentives in our model as we show later. By contrast, the principal's equity concern in their model generates *no* such effects. Thus, a number of our subsequent results (e.g., Propositions 2 through 7) are unlikely to obtain in the Meyer and Mookherjee (1987) framework. Moreover, since envy impacts agents' behavior while the principal's equity concerns do not, envy's effect on optimal contracts is more sensitive to agents' characteristics like risk aversion and action aversion in our model than in theirs.

We have focused on incentive provision through wages. Agents may also use financial markets to mitigate the effect of envy. For example, employees in a public firm can invest in its equity to better align their individual payoffs with firm performance. Note that the additional idiosyncratic risk exposure will make this individually inefficient if agents are risk averse but not envious. However, if agents envy each other, such an investment makes the agent's total payoff more correlated with other agents' payoffs, and may diminish envy arising from a comparison of the total payoffs from wages and investments.[23] This may explain the prevalence of equity-based compensation and 401(k) plans.

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[23] Note that this result will not obtain if envy is based solely on a comparison of wages. Moreover, the extent to which financial markets can be used to mitigate the effect of envy may be limited, particularly in large firms. One reason is that the firm's value, besides being affected by exogenous noise, depends on a large number of individuals, not all of whom are likely to be in an agent's reference group for envy. Thus, tying the agent's payoffs more closely to firm value may impose more risk on him than warranted by the accompanying reduction in envy. Another reason why the scheme may be inefficient is that firm performance captures the average performance of all agents, but an envious agent experiences negative envy-related utility even when he receives the average wage, since in this case some agents are paid more than him.

Lemma 2: *An increase in an agent's outcome causes a greater increase in that agent's wage than in the wage of any other agent.*

The intuition behind this lemma is that even though envy causes an agent's compensation to depend on the performance of others in the group, the incentive effect of the contract is still the dominant force in determining the agent's wage. An agent's compensation must be made more sensitive to his outcome than to those of others in order to incent the agent to provide the desired action.

We now make the following assumption to justify the first-order approach.

Assumption 4: The probability distribution of outcomes follows convexity of the distribution function condition (CDFC). That is, $d^2G(x,a)/da^2 \geq 0 \; \forall x \in \Re, a \in \Re$.

Lemma 3: *A solution to the relaxed problem (5), (7), and (8) also solves the unrelaxed problem (5)-(7).*

The above lemma shows that the first-order approach for solving the optimal wage contract is valid and the optimal solution (10) to the relaxed problem is also a solution to the original unrelaxed problem. The MLRP condition in Assumption 3 and the CDFC condition in Assumption 4 are sufficient to ensure that the expected utility of each agent is concave in his action. Thus, replacing the incentive-compatibility constraint (6) with the first-order condition (8) does not change the principal's problem.

Proposition 2: *When there are two agents who envy each other and the outcomes are independent, the utility of an agent is decreasing in the outcome of the other agent if the first agent's marginal utility from relative wages is positive and the agents are sufficiently more risk averse in absolute wages than in relative wages, i.e.,* $|v''/v'| \geq \left|\{\phi''(y)+\phi''(-y)\}/\phi'(y)\right| \; \forall y \in \Re$. *The utility of an agent is increasing in the outcome of the other agent if the first agent's marginal utility from relative wages is negative or if the agents are sufficiently less risk averse in absolute wages than in relative wages, i.e.,* $|v''/v'| \leq \left|\{\phi''(y)+\phi''(-y)\}/\phi'(y)\right| \; \forall y \in \Re$.

This proposition is intuitive.[24] If an agent's marginal utility from relative wages is negative, which is likely if the agent has fairness-motivated preferences and is earning a higher wage than the other

[24] While we have proved this proposition for the two-agent case, we believe that the intuition extends to any arbitrary number of agents ($n \geq 2$) working for the principal.

agent, then a higher outcome of the other agent increases the first agent's absolute wage and reduces his relative wage. Both effects cause an increase in his utility. If the agent's marginal utility from relative wages is positive, the intuition is as follows. With envy, each agent is exposed to risk unrelated to his own action. An agent's wage declines relative to the other agent's wage when the other agent experiences a higher outcome. This relative-wage risk reduces expected utility because of the asymmetric nature of envy (see (3)). In countering this expected utility reduction, the principal incurs a higher expected contracting cost. The principal can lower this cost by increasing the sensitivity of agent i's wage to the outcome of agent j, but this imposes additional risk on agent i since his utility is concave in absolute wages. Thus, the principal, constrained to make each agent's compensation output-dependent for incentive compatibility, faces a choice between imposing risk through absolute wages and imposing it through relative wages. An increase in agents' risk aversion over absolute wages compared to their risk aversion over relative wages decreases the sensitivity of each agent's wage to the outcome of the other agent. Consequently, this sensitivity may be so low that agent i's wage experiences little increase when the other agent realizes a higher outcome, leading i to suffer a utility decline. But if agents' risk aversion over relative wages is sufficiently high compared to their risk aversion over absolute wages, the optimal wage contract makes the wage of each agent very sensitive to the outcome of the other agent. Each agent's wage then responds positively to higher outcomes for the other agent, leading each agent to experience an increase in utility when the other agent realizes a higher outcome.

Proposition 2 highlights the principal's tradeoff in providing incentives through absolute wages and relative wages. Both absolute and relative wages motivate agents to work harder, but variations in both impose risk on agents for which the principal must compensate them. This implies that the expected wage of an agent should be higher when his wage is more sensitive to his own outcome. The dependence of the agent's expected wage on the sensitivity of his wage to another agent's outcome is not as clear, however. On the one hand it increases the risk of his absolute wages, but on the other hand it decreases the risk of his relative wages. What can be said is that the expected wage of an agent should be increasing in the volatility of his relative wage, conditional on a fixed volatility of his absolute wage.

4. ORGANIZATIONAL DESIGN: IS ENVY GOOD OR BAD FOR THE PRINCIPAL?

This section analyzes whether envy among agents is good or bad for the principal. This question is obviously important if the principal has a choice between agents with varying levels of envy. It may be possible for the principal to learn over time about each agent's degree of envy, so that organizational design decisions may depend on this learning. Additionally, the principal may attempt to control the effect of envy among agents by changing the number of agents working for her or the structure of reporting relationships, thereby influencing the size of the reference group that agents base their envy on. We begin by examining the effects of envy on agents' utilities and action incentives.

Proposition 3: *Keeping wage contracts fixed, an increase in γ, the envy among agents: (i) reduces each agent's maximum expected utility, and (ii) causes agents to choose higher actions if the envy function is increasing in relative wages.*

This result reflects two opposing effects of envy on the payoff of the principal, a positive "incentive effect" and a negative "direct utility" effect. The incentive effect is that envy acts as a motivator. An envious agent works harder because this yields a higher individual outcome relative to the other agents' outcomes, and hence a higher wage relative to the wages of other agents. This result requires that the envy-related utility be an increasing function of the relative wages. The more envious an agent, the greater is his utility from an increase in his wage relative to the wages of others.[25] Thus, envy generates action incentives in and of itself and the principal can employ weaker contractual incentives to elicit the same actions from the agents. Since providing incentives to risk-averse agents is costly, this weakening of incentives lowers expected contracting costs and increases the principal's expected payoff.

The incentive effect of envy implies that envy helps ameliorate the problem of incenting "rich" agents to work hard. Mechanisms like savings and credit markets access allow agents to accumulate

[25] The incentive effect requires that envy-related utility be increasing in one's own consumption. Becker, Murphy, and Werning (2005) assume that an individual's utility is increasing in his consumption as well as his status. The utility from status is somewhat similar to our envy-related utility. The difference is that while consumption levels determine envy-related utility in our model, Becker, Murphy, and Werning assume that status may be independent of consumption or may depend on the consumption of only a few goods. They also assume that higher status increases the marginal utility from consumption. By contrast, in our specification, the marginal non-envy-related utility depends only on absolute consumption and not on relative consumption.

wealth and diminish the incentive effects of contracts (Rogerson (1985b) and Bizer and DeMarzo (1999)). Proposition 3 shows that the incentive effect of envy helps to offset this weakening of incentives.[26]

The direct utility effect of envy arises due to the asymmetry property of envy. Since the increase in the envy-related utility of the agent earning more is less than the decrease in the envy-related utility of the agent earning less, on average envy reduces utility. If the principal does not alter contracts when envy increases, the incentive effect causes agents to work harder while the direct utility effect causes their expected utilities to decline. Note that Proposition 3 holds for optimal contract as well as any wage contract such that an agent's absolute wage as well as his relative wage is increasing in his own outcome.

We have taken as exogenous the actions that the principal induces the agents to take. The incentive effect of envy may cause the principal to induce more envious agents to work harder, and the resulting disutility will reinforce the utility reduction due to the direct utility effect of envy. Thus, the principal will need to compensate more envious agents with higher expected wages. If we take the number of employees in the firm as a proxy of envy[27], this predicts harder work and higher wages in larger firms. While we are not aware of any evidence about how between workers' efforts relate to firm size, there is considerable evidence that compensation increases with firm size (see Idson and Oi (1999)).

Another aspect of envy is that it makes an agent unhappy only because he looks worse by comparison either because a peer experiences a higher outcome by luck or because a peer works harder and generates a higher outcome. But this applies symmetrically to *all* agents, suggesting that the agents could be collectively better off if they all abstained from working harder. This intuition is captured below.

Proposition 4: *With two envious agents, a strictly increasing envy function, and the optimal wage contracts for agents acting independently, the equilibrium action chosen by the agents acting independently (i) exceeds the action they will choose in collusion if they are sufficiently more risk averse*

[26] A related observation is that the pay-for-performance sensitivity offered to executives tends to ignore the stock ownership of these executives (see Baker, Jensen, and Murphy (1988)). The effect of stock ownership on incentives will be mitigated to the extent envy drives incentives of executives and to the extent envy among coworkers is based on differences in wages rather than differences in wealth obtained from other sources such as stock market gains.

[27] It is easy to prove the result in Proposition 3 with an increase in number of agents rather than increase in envy among pairs of agents. We don't include that to conserve space.

in absolute wages than in relative wages, $\left|v''/v'\right| \geq \left|\{\phi''(y)+\phi''(-y)\}/\phi'(y)\right| \; \forall y \in \Re$*, and (ii) is less than the action they will choose in collusion if the reverse is true,* $\left|v''/v'\right| \leq \left|\{\phi''(y)+\phi''(-y)\}/\phi'(y)\right| \; \forall y \in \Re$.

The intuition is that an agent's action imposes an externality on the other agent.[28] When agents choose actions independently in a Nash equilibrium, they do not internalize this effect, similar to the Prisoner's Dilemma problem. Since a higher action by an agent reduces the other agent's expected utility, agents choose higher actions in a Nash equilibrium than under collusion.[29] Envy thus provides a new perspective on the relative benefits of cooperation versus competition that have been explored in the literature (e.g., Itoh (1991) and Ramakrishnan and Thakor (1991)).

Proposition 5: *If a change in envy parameter* γ *does not change the non-envy-related utility or the reservation utility of the agents, then with wage contracts designed to be optimal at the altered* γ*, the following is true: the expected per-agent-payoff of the principal increases with* γ *if the envy function* ϕ *is linear, and decreases with* γ *for sufficiently small values of* γ *when* ϕ *is concave and agents are risk neutral in absolute consumption.*

The intuition is as follows.[30] Unlike Proposition 3, here the principal adjusts contracts to keep them optimal as the degree of envy changes. This means that the principal's expected payoff declines as she compensates agents for the reduction in utility due to the direct effect of envy. A linear (or sufficiently low in risk aversion) envy function leads to a relatively small direct utility effect of envy -- since this effect arises solely from the concavity of the envy-based function -- without adversely impacting the incentive effect of envy. Thus, envy makes the principal better off, indicating that it may be preferable to form a team of agents who envy each other rather than to have individual non-envious

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[28] Although Proposition 4 has been proved for the two-agent case, it can be readily extended to cover *n* agents ($n \geq 2$) if we can take Proposition 2 as holding for $n > 2$.

[29] The possibility of collusion may cause the principal to alter the optimal contract. Proposition 4 assumed the wage contract is kept fixed as the optimal contract for the case when agents act independently.

[30] Proposition 5 requires that the degree of envy among agents does not affect their non-envy-related utility or their reservation utility. That is, $\xi(\gamma)=\xi$ and $U^*(\gamma)=U^*$. If these conditions are not met, complex tradeoffs may arise between envy and other attributes of the agents. The conditions are more likely to hold when environmental shocks cause envy to change for all agents rather than when agents start out with different degrees of envy. Thus, admittedly Proposition 5 is a special result that seems difficult to generalize further.

agents work independently, even when there are *no* output complementarities among agents.[31,32] By contrast, when agents display risk aversion in relative consumption and risk neutrality in absolute consumption, an increase in envy makes the principal worse off, at least at low levels of envy.[33]

Because organizational design may influence how employees view their reference groups for envy, Proposition 5 suggests that optimal organizational design may take the marginal effect of envy into consideration. In particular, envy increases with the number of agents reporting to the principal.[34] The reason is that an increase in number of agents allows an agent to compare herself with more agents and each comparison results in a utility that is concave in relative wages, so the expected envy-related utility declines with more comparisons. Although Proposition 5 is stated for a change in the envy parameter γ for a fixed number of agents, the effect of increasing γ on realized envy is similar to that of increasing the number of agents holding γ fixed. Of course, as the number of agents increases, envy between a pair

[31] The result that the principal could be better off when agents care about relative as well as absolute consumption is specific to envy and is unlikely to obtain with inequality aversion.

[32] Glaeser and Scheinkman (2002) and Sacerdote (2001) discuss how the actions or performances of one's peers may affect one's own actions. In these papers, the reference group is exogenous and fixed, so it is not clear how the size or existence of a peer or reference group affects one's actions.

[33] An extension of our analysis may permit an examination of endogenous organizational design in which the principal chooses either a team of agents or multiple agents working independently for her. The choice of organizational design will optimize the benefit or loss from complementarities as well as envy. Thus, situations in which envy among agents is either beneficial to the principal, or is costly to the principal but the cost is less than the benefits from complementarities, should result in the principal choosing a team of envious agents. The principal should have agents work for her independently when envy among agents imposes a cost on the principal greater than the benefit from complementarities.

[34] Englmaier and Wambach (2005) seem to reach the opposite conclusion. They view social comparisons to be more important in smaller groups, while in our model envy has a bigger impact with larger reference groups. A key difference between the two papers appears to be that the number of envy-inducing comparisons matters in our model but not in Englmaier and Wambach (2005). The two views can be reconciled if an increase in the number of agents, n, lowers γ, the degree of envy in each pairwise comparison, but increases the number of comparisons ($n-1$) each agent performs in order to assess envy-based utility. As long as γ does not decline too rapidly, an increase in n will weaken an agent's envy towards another agent but still have a greater expected impact on the agent's utility. A key underlying assumption in our analysis is that an agent performs separate social comparisons with other agents rather than with the aggregate or an average agent. This is important because a comparison with the aggregate could lead to an opposite result that envy matters more with fewer agents as the uncertainty about the average of other agents' outcomes increases with fewer agents. Further, even if the average wage is kept constant, a change in the distribution of wages of other agents can impact envy. For example, an agent earning an average wage may experience disutility from earning less than high-earners that exceeds her utility from earning more than low-earners. Martin (1981) provides experimental evidence that agents are more concerned about the wages of the highest paid in the group than about the average wage. Buckingham and Alicke (2002) show that individuals place more weight on social comparisons with individuals than with the aggregate. Finally, if the object of envy is multidimensional -- say wage and perquisites -- then agents may focus on the dimension in which they are worse off than others, so *both* agents in a pair may experience disutility from mutual comparison.

of agents *may* diminish, particularly if the number of agents is large enough to impose a cognitive limit on one's ability to compare across all the agents.[35] In assuming that the degree of envy does not decline, we are focusing on smaller organizations where such cognitive constraints are *not* binding. Under this assumption, if envy is marginally costly to the principal, increasing the number of agents may decrease the principal's per-agent payoff.[36] The optimal number of agents in the firm will depend on the tradeoff between the effect of envy and the complementarities between agents' outputs, so the relationship between firm size and profitability may be driven by this tradeoff.

Kaen and Baumann (2003) show that profitability for manufacturing firms is decreasing in the number of employees, controlling for asset size. One explanation for this finding is that an increase in the number of employees worsens envy-related distortions. However, this explanation is empirically difficult to disentangle from the effects of output complementarities or other agency and organizational problems. An alternative test of the effect of envy would be to examine if firm profitability is related to the determinants of envy.[37] Bloom (1999) finds that pay dispersion negatively affects organizational performance (see also Pfeffer and Davis-Black (1992) and Pfeffer and Langton (1993)).

5. IMPLICATIONS OF ENVY FOR PAY-FOR-PERFORMANCE SENSITIVITY

In this section, we examine the impact of envy on the pay-for-performance sensitivity, i.e., the sensitivity of an agent's wage to his own outcome. In Subsection A, we provide a numerical example,

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[35] There is little scientific evidence about how reference groups are formed and how their size impacts the degree of envy. See Salovey and Rodin (1984).

[36] The effect of increasing envy between each pair of agents on the principal's per-agent payoff is similar to increasing the number of agents while holding the envy between each pair of agents fixed. Proposition 5 can easily be proved with an increase in the number of agents rather than an increase in envy. The first part will follow from the fact that with more agents to compare with, each agent will be more motivated to work so the principal can weaken costly incentives. The second part follows because with risk-neutral agents, the first-best can be achieved when there is only one agent. As the number of agents increases, envy reduces the expected utilities of agents, which must be compensated by the principal by paying agents higher expected wages. Interpreting envy as the number of agents avoids the issues related to how the reservation utility of an agent changes when his preferences change. The possible concern that an agent in an organization may not envy all other agents when the organization grows very large does not affect our results as long as the reference group of each agent expands when the organization grows.

[37] We have assumed that an agent's reference group for envy purpose consists of all other agents in the firm and that envy is uniform. This is a simplification as reference groups may be endogenous and people may envy their coworkers, neighbors, or other acquaintances and the intensity of envy may depend on the degree to which one considers the other person similar in background and opportunities (see Ben-Zeev (1992) and Luttmer (2004)). Thus, employee heterogeneity may affect the size of envy-related distortions.

with specific functional forms for the utility functions and the production functions, to illustrate how envy affects the pay-for-performance sensitivity of optimal contracts. For general wage contracts, the pay-for-performance sensitivity depends on the outcome itself, so the rank-ordering of the sensitivities of two wage functions may vary across outcomes. This makes comparison of pay-for-performance sensitivities across different wage contracts not very meaningful. To avoid this problem and for analytical tractability, in Subsection B we examine the special case of linear wage contracts and analyze the impact of envy on the pay-for-performance sensitivity of contracts that are optimal in this case.[38]

A. An Example of Optimal Wage Contracts

We assume there are two agents, 1 and 2. Their utility functions are

$$U_1(W, a_1) = v(w_1) + \gamma\phi(w_1 - w_2) - c(a_1), \text{ and } U_2(W, a_2) = v(w_2) + \gamma\phi(w_2 - w_1) - c(a_2)$$

where $v(w) = \left[pw - \frac{qw^2}{2}\right]$ and $\phi(w) = \left[yw - \frac{zw^2}{2}\right]$.

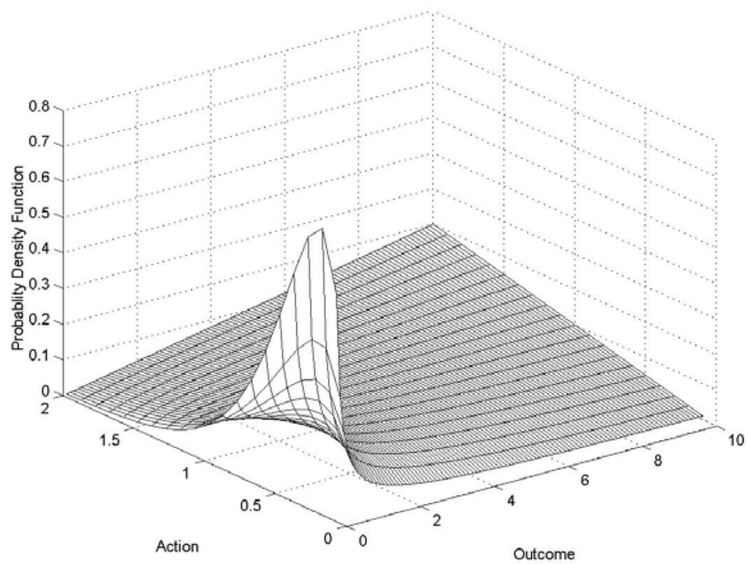
The utility functions yield linear marginal utilities. This simplifies the derivation of optimal wage contracts. The production functions are given by the cumulative distribution function

$$G(x_i, a_i) = \left(\frac{x_i}{10}\right)^{a_i}, \quad i = 1,2 \quad .$$

The above function is suggested by Rogerson (1985a) as an example of a production function satisfying the conditions for the first-order approach to be valid for obtaining optimal contracts in the absence of envy. *Figure 1* shows a plot of the production function.

[38] A related question is how pay-for-performance sensitivity depends on the risk of agents' outcomes. This risk is measured in our model by the variance of the distribution function *g*. A prediction of standard principal-agent theory is that pay-for-performance sensitivity should decline as the risk of outcomes increases. The intuition for this result holds even when agents envy each other, so it is not clear that incorporating envy into preferences has any incremental effect on the relationship between risk and pay-for-performance sensitivity.

Figure 1: Production Function



Under the above assumptions, the optimal contract in (10) satisfies:

$$\frac{1}{p - qw_i + 2\gamma\, z \sum_{j \in \{1,2\}-\{i\}} \left(w_j - w_i\right)} = \alpha + \beta \frac{dg(x_i, a_i)/da_i}{g(x_i, a_i)} \quad \forall i \in \{1,2\}, \text{ which implies:}$$

$$p - qw_i + 2\gamma\, z \sum_{j \in \{1,2\}-\{i\}} \left(w_j - w_i\right) = r_i \equiv \frac{1}{\alpha + \beta \left[\frac{dg(x_i, a_i)/da_i}{g(x_i, a_i)} \right]} \quad \forall i \in \{1,2\}. \qquad (11)$$

The system of linear equations in (11) can be solved to obtain:

$$w_i = \frac{1}{q}\left(p - \frac{qr_i + 2\gamma\, z(r_1 + r_2)}{q + 4\gamma\, z} \right) \quad \forall i \in \{1,2\}.$$

The optimal contract parameters α and β can be solved numerically so that the wage contracts satisfy the individual rationality constraints and the incentive compatibility constraints of the two agents. For this exercise, we assumed $p = 2$, $q = 1$, $y = 5$, and $z = 0.5$. The cost of action is assumed to be equal to the action, and the action vector implemented is (1, 1). *Figures* 2 and 3 plot the numerically-computed optimal wage contracts in the no-envy case and in the envy case with $\gamma = 0.1$.

Figure 2: Optimal Contract with No Envy ($\gamma = 0$)

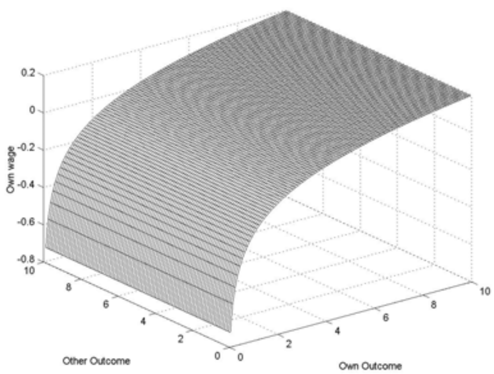


Figure 3: Optimal Contract with Low Envy ($\gamma = 0.1$)

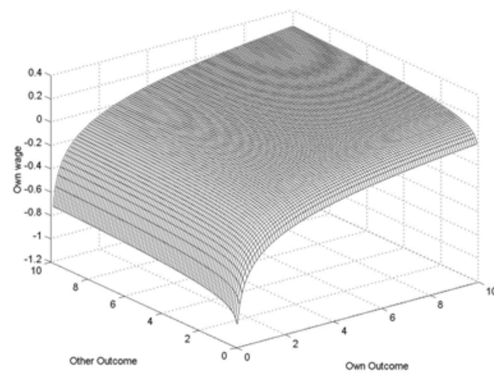


Figure 4: Optimal Contract with High Envy ($\gamma = 1$)

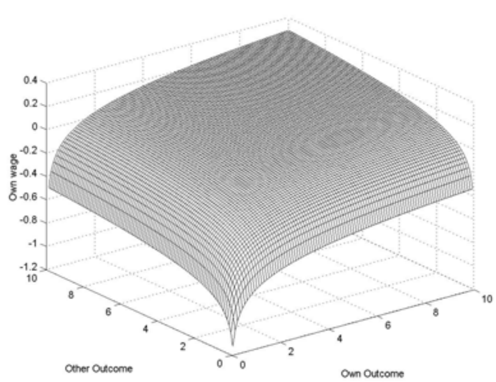


Figure 5: Difference in Pay-for-Performance Sensitivities Across $\gamma = 1$ and $\gamma = 0.1$

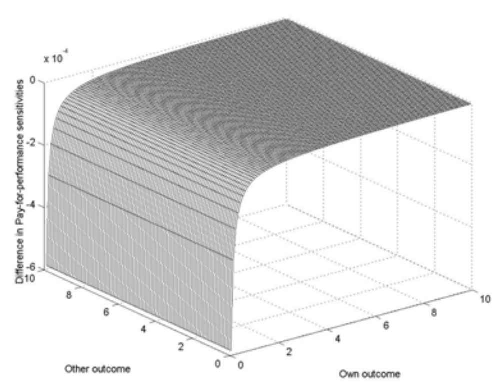


Figure 2 shows that, absent envy, an agent's wage is increasing in his own outcome and is independent of the other agent's outcome, consistent with Holmstrom's (1979) informativeness principle. *Figures* 3 shows that, with envy, an agent's wage is increasing in his own outcome as well as the other agent's outcome, although it is more sensitive to his own outcome. Thus, each agent's wage is increasing in his outcome *relative* to the other agent's outcome. Further, as envy increases from $\gamma = 0.1$ to $\gamma = 1$, the sensitivity of an agent's wage to the *other* agent's outcome increases (*Figure* 4).

We now examine how envy affects the pay-for-performance sensitivity of the optimal contract. Pay-for-performance sensitivity is the agent's incremental wage associated with each additional unit of his own outcome. We examine two cases, $\gamma = 0.1$ and $\gamma = 1$, and then compute the difference in pay-for-performance sensitivities. *Figure 5* plots the pay-for-performance sensitivity with $\gamma = 1$ minus that with $\gamma = 0.1$. It can be seen that this difference is negative for all outcome combinations, suggesting that the pay-for-performance sensitivity of the optimal wage contract declines as envy increases.

B. Envy and Pay-for-Performance Sensitivity for Linear Contracts

Consider the model of the previous section specialized to only two agents, 1 and 2, with preferences represented by (1). Wages are restricted to be linear. Since the agents are ex ante identical, we focus on symmetric contracts. Let the actions that the principal wants the two agents to take be (a^*, a^*). If the agents choose actions (a^*, a^*), the expected outcome of either agent is $\bar{x}$. That is,

$$\bar{x} = \int x_i g(x_i, a^*) \mathrm{d}x_i, \quad i = 1,2 \tag{12}$$

The linear wage contracts can be represented as follows:

$$w_1 = k + l(x_1 - \bar{x}), \quad w_2 = k + l(x_2 - \bar{x}), \tag{13}$$

where k and l are scalars the principal chooses.[39] We refer to k as the agent's fixed wage and l, his share of the unexpected outcome, as his pay-for-performance sensitivity. The principal's problem is

$$\underset{l,m,n}{Min} \quad Z \equiv \int \{w_1(X) + w_2(X)\} g(X, A) dX \tag{14}$$

subject to

[39] Empirical tests of pay-for-performance sensitivity measure it as the sensitivity of the agent's pay to his own performance. Therefore, we define pay-for-performance sensitivity accordingly. We obtain qualitatively similar results when we analyze a more general form of symmetric wage contracts in which the wage of each agent depends linearly on his own outcome as well as on the outcome of the other agent.

$$Q \equiv \int U_1\left(W, a^*\right) g(X, A) dX - U^* = 0 \tag{15}$$

$$R \equiv d\left\{\int U_1\left(W(X), a^*\right) g(X, A) dX\right\} \Big/ da_1 = 0 \tag{16}$$

The individual rationality constraint (15) has been represented as an equality because it will be binding in equilibrium. The principal can change the fixed wage k paid to the agents to ensure that each agent's expected utility exactly equals his reservation utility.

Proposition 6: *For linear contracts with two agents, the principal optimally weakens incentives in response to an increase in the degree of envy by lowering each agent's pay-for-performance sensitivity.*

The intuition is that an increase in envy has two main effects: it increases the marginal cost of providing wage-induced effort incentives, and it makes agents work harder while lowering their expected utilities (Proposition 3). The principal's response to the higher marginal cost of incentive provision is to lower the pay-for-performance sensitivity of both agents, recognizing that the consequent weakening of effort incentives is somewhat attenuated by the agents' envy-based proclivity to work harder. Moreover, to counteract the effect of lower expected utilities, each agent's fixed wage is increased.[40]

Proposition 6 provides a possible explanation for Jensen and Murphy's (1990) empirical finding that the pay-for-performance sensitivity of executives in firms seems to be low relative to what theory would suggest.[41] An alternative explanation is provided by the "multitasking" literature which proposes that an agent's work is multidimensional and if performance measures that are used to provide incentives do not encompass all these dimensions, the agent will distort his effort allocation among the different dimensions to "game" the wage contracts (Holmstrom and Milgrom (1991)). The principal may thus weaken the agent's incentives along a particular dimension in order to avoid the potentially greater cost of the agent making an inefficient effort allocation. By contrast, envy creates incentives of its own, so lowering the pay-for-performance sensitivity results in optimal incentives.

Proposition 6 also yields an implication about the relationship between firm size and pay-for-

[40] Although proved for linear contracts, we believe this result holds more generally.

[41] Of course, calibrating the theoretically-optimal benchmark pay-for-performance sensitivity is difficult.

performance sensitivity. If envy plays a greater role in larger firms with more agents, then the pay-for-performance sensitivity should be higher in smaller firms. This prediction is consistent with the findings of Garen (1985), Rasmusen and Zenger (1990), and Schaefer (1998).

Propositions 1 and 6 offer a possible explanation for wage compression, such as that documented by Landy and Farr (1980), Mohrman and Lawler (1983), and Murphy and Cleveland (1991), which is difficult to rationalize with the standard principal-agent model. Proposition 1 shows that an increase in an agent's outcome increases the wages of *all* agents, and Proposition 6 shows that greater envy reduces the outcome-sensitivity of relative wages. Together they predict a lower cross-sectional variation in wages than one would obtain in the absence of envy; envy has the effect of smoothing wages *across* agents.[42]

Wages are compressed in our model to mitigate the reduction in agents' expected utilities arising from wage disparity. The agents can do little to avoid this envy-related utility reduction other than taking actions that increase their own outcomes. Mui (1995) allows envious firms to retaliate against firms that innovate successfully. If envious agents in our model can sabotage the outcomes of other agents, the principal will have even stronger incentive to compress wages, strengthening Propositions 1 and 6.

6. ROBUSTNESS OF RESULTS TO ALTERNATIVE PREFERENCE SPECIFICATIONS

In this section, we first discuss how envy-based preferences specified in our model compare with those in the recent literature and then briefly discuss how alternative preferences affect our results. For utility function comparisons, we will not distinguish between consumption and wages. The part of utility that depends on one's own wage is the function v in (1). This function appears in different forms in different papers. For example, it is the identity function in Fehr and Schmidt (1999) and Charness and Rabin (2002), and is a weakly increasing and concave function in Bolton and Ockenfels (2000). More

[42] What if the principal is a supervisor who does not set wages but is merely instructed to implement a given wage structure, and outcomes are privately observed by the supervisor? In this case, the supervisor will be asked to rate workers and ratings will serve as the proxy for outcomes in determining wages. If the supervisor has to absorb a cost that increases with agents' envy, he will tend to be lenient in assigning ratings. This cost could either be a direct cost of higher wage payment to compensate agents for their envy-related utility loss, as in our analysis, or an indirect cost related to the time and effort the supervisor spends in dealing with agents who are dissatisfied with their ratings. This will lead to ratings compression, which has been empirically observed (e.g., Rothe (1949) and Stockford and Bissel (1949)). Wage and ratings compression will also arise in a setting with inequality aversion rather than envy.

important, however, is the component of utility that depends only on a comparison with other individuals. We take this component to be the difference between an agent's utility and the utility the agent would have if everyone else in the reference group consumed the same as the agent. It is this component of utility where the most important differences lie. These are discussed below.

A. Inequality-Averse Preferences: Fehr and Schmidt (1999) and Bolton and Ockenfels (2000) specify preferences that Charness and Rabin (2002) refer to as "difference-averse" and we refer to as "inquality-averse." This is because, holding fixed an agent's own consumption, the agent prefers to minimize the difference between his own consumption and that of others. These preferences differ from ours in that inequality aversion creates a negative marginal utility from higher relative payoff, whereby envy creates a positive marginal utility from higher relative payoff. The specification in (1) will be consistent with inequality aversion if $\phi'(x) > 0$ for $x < 0$ and $\phi'(x) < 0$ for $x > 0$.

More specifically, Fehr and Schmidt's (1999) preferences represent a special case of (1) with a piecewise linear envy function ϕ, and they also satisfy constraints (2) and (3). The Bolton and Ockenfels (2000) preferences are similar to (1) with a concave ϕ that peaks at $\phi(0) = 0$. Their specification differs from ours in two ways. First, each agent in their model compares his wage only to the average wage of all other agents, whereas in (1) the comparison is to the distribution of wages of *all* agents. The comparison to the average wage will affect our comparative statics results about the number of agents. An increase in the number of agents strengthens the effects of envy under our specification but may weaken the effects of envy when the comparison is to the average wage because the average wage will be less variable with more agents (see footnote 34). Second, Bolton and Ockenfels use the *ratio* of one's wage to the average wage as the basis of comparison, whereas we use the difference. Using a ratio has some advantages. For example, standard functional forms like the Cobb-Douglas and the logarithmic function are not defined for zero or negative wage differences. However, our use of a ratio *per se* would *not* have affected any of our key results since the negative direct utility effect of wage variations will continue to hold.

As long as (2) is satisfied - - even when an agent experiences disutility from a higher relative payoff, his total utility is increasing in his own payoff - - many of our results will continue to hold with inequality-averse preferences. However, Propositions 3 and 4 may not hold. Proposition 3 shows that an increase in envy, keeping agents' wage contracts unaltered, has two effects. First, it lowers each agent's expected utility and second, it causes each to choose a higher action because of a preference for higher relative payoffs. The first effect will persist with inequality-averse preferences, but the second effect may not. Proposition 4 specifies conditions under which agents choose higher (or lower) actions than under collusion. A higher action by agent *i* is more likely to increase agent *j*'s utility with inequality aversion than with envy. Hence, the conditions under which agents will choose lower actions independently than with collusion will be less restrictive with inequality aversion than those in Proposition 4.

B. One-Sided Envy-Based Preferences: We have assumed that envy affects an agent's utility regardless of his own relative performance. An alternative view is that relative-consumption-based utility declines when one's payoff is below that of others, but there is no utility gain when one's payoff exceeds that of others. Such preferences would be consistent with (1) if the envy function ϕ is:

$$\phi(x) = \max(0, \psi(x)), \tag{17}$$

where $\psi' > 0$, $\psi'' < 0$ and $\psi(0) = 0$. While this bifurcation of ϕ into two regions of relative payoffs is unrealistically abrupt, it nonetheless satisfies our assumptions on ϕ, so our results hold.

C. Envy of Action-Adjusted Wages: In our model, the envy experienced by agents is independent of presumed action choices, which raises the question of why an agent should feel envious of someone who worked harder and was "deservedly" paid more. Alternatively, agents could compare "action-adjusted" wages, as in Adams (1963), so agent *i* would be less averse to agent *j*'s higher wage realization if agent *j* worked harder. This equity-based motive for inter-agent comparison is not an issue in our model because all agents are ex-ante identical, make identical action choices, and get the same wage contracts; ex-post wage differences arise solely due to chance. Nonetheless, if we introduce action-adjusted envy, each agent will have to compute his utility on the basis of his *beliefs* about other agents' unobservable action choices. With identical agents, all agents are expected to choose the same action, so agents' expected utilities do *not* change, but the agents will experience envy-related effort disutility. This will make effort incentives costlier for the principal and thus reduce the positive incentive effect of envy.

D. No Ex-Ante Expectation of Envy: We have made the natural assumption that individuals rationally anticipate the effect of envy on their ex-post utility. This is important because the agents' action choices, participation decisions and consequently the wage contracts offered by the principal all depend on their beliefs about preferences as specified in (1). If we were to make the extreme assumption that agents realize ex-post envy but do *not* anticipate this, then envy will play *no* role and all of our results will reduce to the ones in the principal-agent model with standard preferences. Alternatively, if agents *underestimate* the ex-post effect of envy, then the parameter γ in the beliefs about preferences (1) will be less than the true parameter. All our results will still hold qualitatively, albeit with diminished strength. For example, there will be less wage compression when agents are known to underestimate γ.

E. Cross-Sectional Variation in Envy: We now extend the model of Section 2 to incorporate variations in envy across agents. Our assumption in the main model was that all agents in the firm envy each other to the same degree. Now, we allow the degree of envy with which the agents in a pair envy each other to vary across pairs. This accommodates agent-specific reference groups and agents who envy some agents more than others. The main model is retained but agents' preferences change. Agent *i*'s utility is:

$$U_i(W, a_i) = v(w_i) + \sum_{j \in N - \{i\}} \gamma_{ij} \phi(w_i - w_j) - c(a_i). \tag{18}$$

The constant $\gamma_{ij} \geq 0$ with $\gamma_{ij} = \gamma_{ji}$; higher values of γ_{ij} correspond to greater envy among agents *i* and *j*. The reservation utility of agent *i* is U_i^*. The reservation utility may depend on degree of envy and may differ across agents. It seems likely that more envious agents will have lower expected utilities from outside options and so also lower reservation utilities but this has no effect on the results of this section.

Proposition 7: *The wage of an agent is increasing in his own outcome and non-decreasing in the outcomes of all other agents, including those the agent does not envy. The wage of agent i is independent of the outcome of agent j if and only if agents can be partitioned into two groups such that agents i and j* *fall in two different reference groups, with agents from different groups not envying each other.*

What is surprising about this proposition is that agent *i*'s wage may depend on agent *j*'s outcome even when these agents do *not* envy each other. The intuition is as follows. The wage of an agent *k* who envies agent *j* will clearly depend on agent *j*'s outcome (see the intuition for Proposition 1). However, if agent *i* envies agent *k* but not agent *j*, then agent *i*'s wage will also depend on agent *j*'s outcome. This is because the principal can lower expected wages by reducing variations in the wages of agents *k* and *j* as well as variations in the wages of agents *i* and *k*. Therefore, any risky outcome that increases agent *j*'s wage, such as agent *j*'s outcome, must also increase the wages of agents *i* and *k*.

Proposition 7 suggests that agents can be divided into mutually exclusive groups such that the wage of an agent in a group depends on the outcomes of all other agents in the group but not on the outcomes of agents in other groups. These reference groups are consistent with the observation of Baker, Jensen, and Murphy (1988) that pay in organizations tends to be based on an agent's level in the hierarchy, and that a promotion changes the agent's level in the hierarchy as well as his reference group. Our analysis shows that even if agents in a level envy *only some* agents in their level, the wage of *every* agent will depend on the outcomes of *all* the agents in that level.

We believe that reference levels of agents may change even in the absence of promotions. This will happen when their performance is much higher or much lower than that of their reference group members. Such performance differences can cause agents to implicitly put themselves in different reference categories. Our model predicts that the sensitivity of an agent's wage to the outcome of another agent will be a decreasing function of the absolute difference in the past performances of the two agents.

7. ENVIOUS BEHAVIOR AS OUTCOME OF INFORMATIONAL FRICTIONS

We have taken the view thus far that envy is biologically hardwired. But are there alternative ways to rationalize envy solely on economic grounds? Why should a worker who does not believe he has been treated unfairly envy someone who is more highly rewarded? Identification of the economic mechanism by which people develop envy-based preferences, although not essential for our results, is interesting in its own right. In particular, it can help us understand the economic rationale for why a worker would envy someone who gets paid more according to a rule that applied to him as well.

In this section, we develop a model to show how seemingly envious behavior can arise as a result of information asymmetries that cause agents to care about each other's consumption. The model shows that agents' equilibrium utilities are declining in the wages of their peers. This can be interpreted in two ways. One is that although agents care *only* about their own consumption, information frictions cause them to behave as if they were envious. Another interpretation is that agents have developed envy-based preferences such that agents' behavior based on such preferences creates the illusion of a conscious response to informational frictions even when such frictions are absent. Thus, envy-based preferences may, like reflex actions, be short-cuts to dealing with the environment.

A Model of "Envy" Based on the Information Content of Agents' Wages:

A team of n ex ante identical agents, indexed 1 through n, works for a risk-neutral principal who maximizes her expected payoff net of agents' wages. Let $N \equiv \{1, \ldots, n\}$. Agent $i \in N$ has unknown ability θ_i. Agents' abilities are independently and identically distributed with marginal probability density function h. Agent i chooses a privately-observed action $a_i \in \Re$, and has an outcome $x_i \in \Re$ with probability density function $g(x_i, a_i, \theta_i)$ that displays monotone likelihood ratio property; for $\theta_H > \theta_L$, $g(x, a, \theta_H) / g(x, a, \theta_L)$ increases as x increases. An agent's outcome is observed by the agent and the principal and possibly other agents. Abilities, actions, and outcomes are represented by the sets $\Theta \equiv (\theta_1, \ldots, \theta_n)$, $A \equiv (a_1, \ldots, a_n)$ and $X \equiv (x_1, \ldots, x_n)$. Let $g(X, A, \Theta) \equiv \prod g(x_i, a_i, \theta_i)$ and $h(\Theta) \equiv \prod h(\theta_i)$.

The total payoff, $f(X)$, is to be shared between the principal and the agents, and it is a symmetric function of the n outcomes. That is, $f(\hat{x}_1, \hat{x}_2, \ldots, \hat{x}_n) = f(\bar{x}_1, \bar{x}_2, \ldots, \bar{x}_n)$ if $(\bar{x}_1, \bar{x}_2, \ldots, \bar{x}_n)$ is a permutation of $(\hat{x}_1, \hat{x}_2, \ldots, \hat{x}_n)$. Since agents are ex ante identical, the total payoff depends only on the realized outcomes and not on the identity of an agent associated with an outcome. The agents' wages are denoted as $W \equiv (w_1, \ldots, w_n)$. In addition to his outcome-dependent wage, each agent obtains a private benefit B from working with the principal.[43] Agents maximize expected utility from wages and private benefits, given by $\nu(w_i + B)$ for agent i, minus the disutility from action, given by $c(a_i)$ for agent i.

The principal's problem is to choose agents' actions A and wage contracts $W : \Re^n \to \Re^n$ to maximize her expected net payoff:

$$\int \left\{ f(X) - \sum_{i \in N} w_i(X) \right\} g(X, A, \Theta) h(\Theta) dX \tag{19}$$

subject to the agents' individual rationality (IR) constraints

$$\int \nu(w_i(X) + B) g(X, A, \Theta) h(\Theta) dX - c(a_i) \geq U^* \quad \forall i \in N \tag{20}$$

and the agents' incentive compatibility (IC) constraints

$$\begin{aligned} &\int \nu(w_i(X) + B) g(X, A, \Theta) h(\Theta) dX - c(a_i) \geq \\ &\quad \int \nu(w_i(X) + B) g(X, (a_1, ..., a_{i-1,} a_i', a_{i+1}, ..., a_n), \Theta) h(\Theta) dX - c(a_i') \quad \forall i \in N, a_i' \in \ \Re . \end{aligned} \tag{21}$$

The optimal wage contract is: $w_i = w(x_i) - B$. An agent's wage depends only on his own output because agents care only about their own wages, and other agents' outcomes are uninformative about an agent's action. The principal adjusts wages based on agents' private benefits. Thus, wage functions are identical for all agents and each agent's wage is a function of his own outcome minus his private benefit.

Now, consider an "outsider" who cannot observe the agents' outcomes or their private benefits, and therefore infers agents' abilities and private benefits from observing their wages. The posterior belief of the outsider about B is given by:

$$\psi'(B|W) = \frac{\prod_i k(w_i + B, \alpha^*) \psi(B)}{\int_{-\infty}^{\infty} \left(\prod_i k(w_i + \hat{B}, \alpha^*) \right) \psi(\hat{B}) d\hat{B}} \tag{22}$$

[43] $B < 0$ represents cost to agents.

where $k(w_i + B, \alpha)$ is the probability density function of an agent's total compensation (wages and private benefit) given by $k(w(x), \alpha) \equiv (w'(x))^{-1} \int_{\theta} g(x, \alpha, \theta) h(\theta) d\theta$ and α^* is the equilibrium action of each agent. The outsider simultaneously updates his beliefs about the expected ability of agent *i* as:

$$g'(\theta_i) = \frac{h(\theta_i) \int_{-\infty}^{\infty} g\left(w^{-1}(w_i + B), \alpha^*, \theta_i\right) \psi'(B) dB}{\int_{\hat{\theta}_i} \int_{-\infty}^{\infty} h(\hat{\theta}_i) g\left(w^{-1}(w_i + B), \alpha^*, \hat{\theta}_i\right) \psi'(B) dB d\hat{\theta}_i} \qquad (23)$$

The above equation shows that the outsider assesses an agent's ability to be higher if he assesses the private benefit *B* to be higher. The assessment of *B*, however, depends on the observed wages of *all* the agents. For a fixed outcome of an agent, the agent's wage is decreasing in the private benefit. This suggests a negative relationship between observed wages and the outsider's inference about *B*. We formalize this with the following assumption.

Assumption 5: An outsider's posterior distribution of private benefit *B* when agent *i*'s wage is w^L first-order-stochastically-dominates the outsider's posterior distribution of *B* when agent *i*'s wage is $w^H > w^L$.

Lemma 4: *Assumption 5 holds if the probability distribution of wages under equilibrium is log-concave.*

The above lemma shows that when an agent's wage has a log-concave distribution, then an increase in the agent's wage lowers the outsider's estimate of the private benefit. It is reasonable to assume that the probability distribution of outcomes is log-concave since admissible distributions include the uniform, the (truncated) normal, and the (truncated) exponential. The wage distribution will also be log-concave as long as the wage function is not too convex in the outcome. Note that log-concavity of the wage distribution is a sufficient condition, but not necessary, for Assumption 5 to hold.

Proposition 8: *The outsider's posterior distribution of agent i's ability when agent j earns a low wage w^L first-order-stochastically-dominates the posterior distribution with agent j earning a high wage $w^H > w^L$.*

The above proposition shows that an outsider's assessment of an agent's ability depends not just on his wage but also on the wages of other agents. His assessment of the agent's ability is lowered when another agent's wage increases. Suppose each agent's expected utility is increasing in the outsider's assessment of his ability, possibly because this assessment influences the agent's future reservation utility or wage. Then, although the agent has no direct disutility from the higher wages of other agents, holding fixed the outsider's assessment of his ability, he nonetheless cares about other agents' wages because the outsider's assessment of his ability is decreasing in the other agents' wages.[44] The reduced form of this relationship can lead to envy-like preferences in our model. Thus, a friction like the unobservability of a common payoff-germane attribute of agents can lead to seemingly envious behavior.

9. CONCLUSION

We have introduced envy into agents' preferences and derived optimal incentive contracts in this setting. These contracts display properties different from those predicted by standard principal-agent theory. Our results help to partially bridge the gap between the theory and real-world contracts.

In addition to characterizing optimal incentive contracts, our analysis also reveals that envy has both negative and positive effects. The negative effect is well known. Envious agents make themselves worse off, and they may also engage in destructive behavior (Mui (1995)). But our analysis also highlights the bright side of envy: it induces agents to work harder. That is, "keeping up with the Joneses" may not be all bad. The interaction between these two effects means that envy among agents can make the principal worse off sometimes and better off other times.[45] While our analysis assumes envy is biologically hardwired into preferences, we have also provided a model in which asymmetric information causes agents who care only about their own consumption *per se* to behave as if they are envious.

We believe that the issue of optimal contract design with envious agents is an important one and deserving further scrutiny. For example, it would be interesting to examine the implications of having an envious principal or agents who envy each other as well as the principal.

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[44] Of course, envy-like behavior from agents' concerns about outsider's assessment of ability changes the wage determination problem faced by the principal and would may change optimal contracts. In particular, an agent's wage may now depend on outcomes of other agents. However, as long as wages are decreasing in private benefits, Proposition 8 will continue to hold.

[45] The interaction between these two effects formalizes the intuition that incentive provision is inherently "unfair" in that it tends to increase wage dispersion, and "fairness" is inherently inimical to incentives.

APPENDIX

Proof of Lemma 1: Suppose $\beta \le 0$. Fix X and $l \in N$. Then, from Assumption 3 and (10),

$$\frac{d}{dx_l}\left(v'(w_i)+\gamma\sum_{j\in N-\{i\}}\{\phi'(w_i-w_j)-\phi'(w_j-w_i)\}\right)\ \begin{cases} =0 & \text{if } i\ne l \\ \ge 0 & \text{if } i=l \end{cases} \quad \forall i\in N.$$

Simplifying,

$$v''(w_i)\frac{dw_i}{dx_l}+\gamma\sum_{j\in N-\{i\}}\left(\phi''(w_i-w_j)+\phi''(w_j-w_i)\right)\left(\frac{dw_i}{dx_l}-\frac{dw_j}{dx_l}\right)\ \begin{cases} =0 & \text{if } i\ne l \\ \ge 0 & \text{if } i=l \end{cases} \quad \forall i\in N. \tag{A-1}$$

Substituting $k\in\arg\max_{i\in N}\frac{dw_i(X)}{dx_l}$ for i in (A-1),

$$v''(w_k)\frac{dw_k}{dx_l}\ge-\gamma\sum_{j\in N-\{i\}}\left(\phi''(w_k-w_j)+\phi''(w_j-w_k)\right)\left(\frac{dw_k}{dx_l}-\frac{dw_j}{dx_l}\right)\ge 0.$$

Thus,

$$\frac{dw_i}{dx_l}\le\frac{dw_k}{dx_l}\le 0. \tag{A-2}$$

Further,

$$\frac{dw_l}{dx_l}\le\frac{dw_i}{dx_l}\quad \forall i,l\in N. \tag{A-3}$$

If this is not true, there exists $k\in\arg\min_{i\in N}\frac{dw_i}{dx_l}, k\ne l.$ From (A-1),

$$v''(w_k)\frac{dw_k}{dx_l}=-\gamma\sum_{j\in N-\{k\}}\left(\phi''(w_k-w_j)+\phi''(w_j-w_k)\right)\left(\frac{dw_k}{dx_l}-\frac{dw_j}{dx_l}\right)<0$$

where the inequality follows from concavity of ϕ and definition of k. Further, concavity of v implies $dw_k/dx_l > 0$, which contradicts (A-2). Inequalities (A-2) and (A-3) together imply that the utility of an agent is non-increasing in his outcome. Since higher actions lead to higher outcomes and agents experience disutility from actions, each agent can increase his expected utility by choosing a lower action, which means that the contract cannot implement any action $a_i > -\infty$. Hence, we must have $\beta > 0$. □

Proof of Proposition 1: Fix X and $l \in N$. From Assumption 3 and (10),

$$\frac{d}{dx_l}\left(v'(w_i)+\gamma\sum_{j\in N-\{i\}}\left\{\phi'(w_i-w_j)-\phi'(w_j-w_i)\right\}\right)\quad\begin{cases}=0 & \text{if } i\neq l\\ <0 & \text{if } i=l\end{cases}\quad\forall i\in N\,.$$

Simplifying,

$$v''(w_i)\frac{dw_i}{dx_l}+\gamma\sum_{j\in N-\{i\}}\left(\phi''(w_i-w_j)+\phi''(w_j-w_i)\right)\left(\frac{dw_i}{dx_l}-\frac{dw_j}{dx_l}\right)\quad\begin{cases}=0 & \text{if } i\neq l\\ <0 & \text{if } i=l\end{cases}\quad\forall i\in N\,. \tag{A-4}$$

Substituting $k\in\arg\min_{i\in N}\frac{dw_i(X)}{dx_l}$ for *i* in (A-4),

$$v''(w_k)\frac{dw_k}{dx_l}\leq-\gamma\sum_{j\in N-\{i\}}\left(\phi''(w_k-w_j)+\phi''(w_j-w_k)\right)\left(\frac{dw_k}{dx_l}-\frac{dw_j}{dx_l}\right)\leq 0\,.$$

Thus, $\frac{dw_k}{dx_l}\geq 0$. Further, $\frac{dw_k}{dx_l}=0$ is possible only if both of the above inequalities are equalities. In particular, this requires $\frac{dw_i}{dx_l}=0\ \forall i\in N$ which contradicts (A4) for the case of *i* = *l*. Thus, we must have $\frac{dw_i}{dx_l}\geq\frac{dw_k}{dx_l}>0\ \forall i\in N$. This establishes the proof for the envy case. See Holmstrom (1979) or Green and Stokey (1983) for the no-envy case. □

Proof of Lemma 2: Fix *X* and $l\in N$. Suppose $\frac{dw_l}{dx_l}\leq\frac{dw_i}{dx_l}$ for some $i\in N$. Consider $k\in\arg\max_{i\in N}\frac{dw_i}{dx_l}, k\neq l$. From (10),

$$\frac{d}{dx_l}\left(v'(w_k)+\gamma\sum_{j\in N-\{k\}}\left\{\phi'(w_k-w_j)-\phi'(w_j-w_k)\right\}\right)\quad=0\,.$$

Rearranging,

$$v''(w_k)\frac{dw_k}{dx_l}=-\gamma\sum_{j\in N-\{k\}}\left(\phi''(w_k-w_j)+\phi''(w_j-w_k)\right)\left(\frac{dw_k}{dx_l}-\frac{dw_j}{dx_l}\right)\geq 0$$

where the inequality follows from concavity of ϕ and definition of *k*. Further, concavity of *v* implies $dw_k/dx_l\leq 0$, which contradicts Proposition 1. □

Proof of Lemma 3: Consider the wage contract *W* that solves the relaxed problem. The set of feasible contracts for the relaxed problem includes the set of feasible contracts for the unrelaxed problem. If we can show that *W* lies in the constraint set of the unrelaxed problem, *W* will minimize expected wages over the set of contracts for the unrelaxed problem because it minimizes expected wages over the set of contracts for the relaxed problem. Thus, it is sufficient to show that *W* satisfies (6). Agent *i*'s expected utility is

$$\int U_i\left(W(X), a_i\right) g(X, A)\, dX = \int_{X_{-i}} R_i\left(X_{-i}, a_i\right) g\left(X_{-i}, A_{-i}\right) dX_{-i}\ , \tag{A-5}$$

where R_i, the expected utility of agent *i* conditional on the outcomes of other agents, is given by

$$R_i\left(X_{-i}, a_i\right) = \int_{x_i} U_i\left(W(X), a_i\right) g\left(x_i, a_i\right) dx_i$$

$$= \int_{x_i} \left\{ v_i\left(w_i(X)\right) + \gamma \sum_{j \in N - \{i\}} \phi\left(w_i(X) - w_j(X)\right) \right\} g\left(x_i, a_i\right) dx_i - c\left(a_i\right)$$

Using integration by parts,

$$R_i\left(X_{-i}, a_i\right) = \lim_{x_i \uparrow \infty} \left\{ v\left(w_i(X)\right) + \gamma \sum_{j \in N - \{i\}} \phi\left(w_i(X) - w_j(X)\right) \right\} - c\left(a_i\right)$$

$$- \int_{x_i} \left\{ v_i'\left(w_i(X)\right) \frac{dw_i}{dx_i} + \gamma \sum_{j \in N - \{i\}} \phi'\left(w_i(X) - w_j(X)\right) \left(\frac{dw_i}{dx_i} - \frac{dw_j}{dx_i} \right) \right\} G\left(x_i, a_i\right) dx_i$$

Differentiating twice with respect to action a_i, we get

$$\frac{\partial^2}{\partial a_i^2} R_i\left(X_{-i}, a_i\right)$$

$$= -c''\left(a_i\right) - \int_{x_i} \left\{ v_i'\left(w_i(X)\right) \frac{dw_i}{dx_i} + \gamma \sum_{j \in N - \{i\}} \phi'\left(w_i(X) - w_j(X)\right) \left(\frac{dw_i}{dx_i} - \frac{dw_j}{dx_i} \right) \right\} \left\{ \frac{d^2}{da_i^2} G\left(x_i, a_i\right) \right\} dx_i$$

$$< 0\,. \tag{A-6}$$

The inequality follows because the integrand is positive. The term inside the second set of braces is positive by Assumption 4. We now show that the terms inside the first set of braces, reproduced below, are also positive.

$$v_i'\left(w_i(X)\right) \frac{dw_i}{dx_i} + \gamma \sum_{j \in N - \{i\}} \phi'\left(w_i(X) - w_j(X)\right) \left(\frac{dw_i}{dx_i} - \frac{dw_j}{dx_i} \right).$$

If $\phi' \geq 0$ then the above expression is positive because for agent *i*, the absolute wage (Proposition 1) as well as the wage relative to other agents (Lemma 2) is increasing in the outcome of agent *i*. If $\phi' < 0$ then

$$v_i'\left(w_i(X)\right) \frac{dw_i}{dx_i} + \gamma \sum_{j \in N - \{i\}} \phi'\left(w_i(X) - w_j(X)\right) \left(\frac{dw_i}{dx_i} - \frac{dw_j}{dx_i} \right)$$

$$> v_i'\left(w_i(X)\right) \frac{dw_i}{dx_i} + \gamma \sum_{j \in N - \{i\}} \phi'\left(w_i(X) - w_j(X)\right) \frac{dw_i}{dx_i} > 0\,.$$

The first inequality holds because wage of each agent j is increasing in the outcome of agent i (Proposition 1) while the second inequality follows from (2) and Proposition 1. Substituting (A-6) in (A-5),

$$\frac{\partial^2}{\partial a_i^2}\int U_i(W(X),a_i)g(X,A)dX = \int_{X_{-i}} \frac{\partial^2}{\partial a_i^2} R_i(X_{-i},a_i)g(X_{-i},A_{-i})dX_{-i} < 0 .$$

Thus, the expected utility of the agent under the wage contract W is concave. So if W satisfies the first-order condition (8), it must also satisfy the global maximum condition (6). □

Proof of Proposition 2: Differentiating (10) for $i = 1$ with respect to x_2,

$$v''(w_1)\frac{dw_1}{dx_2} + \gamma(\phi''(w_1 - w_2) + \phi''(w_2 - w_1))\left(\frac{dw_1}{dx_2} - \frac{dw_2}{dx_2}\right) = 0 . \tag{A-7}$$

Differentiating agent 1's expected utility with respect to x_2,

$$\begin{aligned}\frac{\partial}{\partial x_2}U_1(W(X),a_1) &= v'(w_1)\frac{dw_1}{dx_2} + \gamma\phi'(w_1 - w_2)\left(\frac{dw_1}{dx_2} - \frac{dw_2}{dx_2}\right) \\ &= \frac{v'(w_1)}{v''(w_1)}v''(w_1)\frac{dw_1}{dx_2} \\ &\quad + \gamma\frac{\phi'(w_1 - w_2)}{\{\phi''(w_1 - w_2) + \phi''(w_2 - w_1)\}}\{\phi''(w_1 - w_2) + \phi''(w_2 - w_1)\}\left(\frac{dw_1}{dx_2} - \frac{dw_2}{dx_2}\right) .\end{aligned}$$

If $|v''/v'| \geq |\{\phi''(y) + \phi''(-y)\}/\phi'(y)|$, then $\phi'(y)/\{\phi''(y) + \phi''(-y)\} \leq v'/v''$. Thus,

$$\frac{\partial}{\partial x_2}U_1(W(X),a_1) \leq \frac{v'(w_1)}{v''(w_1)}\left\{v''(w_1)\frac{dw_1}{dx_2} + \gamma(\phi''(w_1 - w_2) + \phi''(w_2 - w_1))\left(\frac{dw_1}{dx_2} - \frac{dw_2}{dx_2}\right)\right\} = 0$$

where the equality follows from (A-7). The proof for the second part of the Proposition is similar. □

Proof of Proposition 3: Consider a wage contract W that implements action A when the envy parameter is γ_L. We assume that that the absolute wage of agent i as well as his wage relative to every other agent is increasing in agent i's outcome for each agent i. From Proposition 1 and Lemma 2, optimal wage contract satisfies these conditions. Suppose the envy parameter is changed to $\gamma_H > \gamma_L$. We shall first show that any agent can increase his expected utility by choosing a marginally higher action. Next, we shall show that concavity of an agent's expected utility in his action is sufficient to ensure a higher optimal action choice. Since W implements A when $\gamma = \gamma_L$, the agent's incentive compatibility condition is

$$\partial\left\{\int U_i(W(X),a_i;\gamma_L)g(X,A)dX\right\}/\partial a_i$$

$$= \int\left\{v(w_i)+\gamma_L \sum_{j\in N-\{i\}}\phi(w_i-w_j)\right\}\frac{dg(X,A)}{da_i}dX - c'(a_i) = 0 \quad \forall i\in N \tag{A-8}$$

We now show that the action choice A is not incentive compatible for the agents at the higher envy level γ_H.

$$\partial\left\{\int U_i(W(X),a_i;\gamma_H)g(X,A)dX\right\}/\partial a_i$$

$$= \int\left\{v(w_i)+\gamma_H \sum_{j\in N-\{i\}}\phi(w_i-w_j)\right\}\frac{dg(X,A)}{da_i}dX - c'(a_i).$$

Substituting (A-8) into the above and then changing the order of integration we obtain,

$$\partial\left\{\int U_i(W(X),a_i;\gamma_H)g(X,A)dX\right\}/\partial a_i$$

$$= (\gamma_H-\gamma_L)\int \sum_{j\in N-\{i\}}\phi(w_i-w_j)\frac{dg(X,A)}{da_i}dX$$

$$= (\gamma_H-\gamma_L)\int_{X_{-i}}\left[\sum_{j\in N-\{i\}}\int_{x_i}\phi(w_i-w_j)\frac{dg(x_i,a_i)}{da_i}dx_i\right]g(X_{-i},A_{-i})dX_{-i} > 0 \quad \forall i\in N$$

where the last inequality follows because the inner integral is positive as explained ahead. The inner integrand is a product of three functions, $\phi(w_i-w_j)$, $(dg(x_i,a_i)/da_i)/g(x_i,a_i)$, and $g(x_i,a_i)$. The first two functions are monotonically increasing in x_i (from our assumption about W and Assumption 3) and the third is positive, so by Chebyshev's inequality (see Mitrinovic and Vaic (1970), Theorem 10, p. 40), we have

$$\int_{x_i}\phi(w_i-w_j)\frac{dg(x_i,a_i)}{da_i}dx_i \geq \int_{x_i}\phi(w_i-w_j)g(x_i,a_i)dx_i\int_{x_i}\frac{dg(x_i,a_i)}{da_i}dx_i$$

$$= \int_{x_i}\phi(w_i-w_j)g(x_i,a_i)dx_i\,\frac{d}{da_i}\int_{x_i}g(x_i,a_i)dx_i = \int_{x_i}\phi(w_i-w_j)g(x_i,a_i)dx_i \times \frac{d}{da_i}1 = 0.$$

Next, we show that each agent's expected utility is concave in his own action.

$$\partial^2\left\{\int U_i(W(X),a_i;\gamma_H)g(X,A)dX\right\}/\partial a_i^2$$

$$= \int\left\{v(w_i)+\gamma_H \sum_{j\in N-\{i\}}\phi(w_i-w_j)\right\}\frac{d^2g(X,A)}{da_i^2}dX - c''(a_i)$$

$$= \int_{X_{-i}}\left[\int_{x_i}\left\{v(w_i)+\gamma_H \sum_{j\in N-\{i\}}\phi(w_i-w_j)\right\}\frac{d^2g(x_i,a_i)}{da_i^2}dx_i\right]g(X_{-i},A_{-i})dX_{-i} - c''(a_i).$$

It is sufficient to show that the inner integral is negative.

$$\int_{x_i}\left\{v(w_i)+\gamma_H\sum_{j\in N-\{i\}}\phi(w_i-w_j)\right\}\frac{d^2g(x_i,a_i)}{da_i^2}dx_i$$
$$=-\int_{x_i}\frac{d}{dx_i}\left\{v(w_i)+\gamma_H\sum_{j\in N-\{i\}}\phi(w_i-w_j)\right\}\frac{d^2G(x_i,a_i)}{da_i^2}dx_i$$
$$=-\int_{x_i}\left\{v'(w_i)\frac{dw_i}{dx_i}+\gamma_H\sum_{j\in N-\{i\}}\left(\frac{dw_i}{dx_i}-\frac{dw_j}{dx_i}\right)\phi'(w_i-w_j)\right\}\frac{d^2G(x_i,a_i)}{da_i^2}dx_i$$
$$<0.$$

The inequality follows because the integrand is positive. The first term in the braces in the integrand is positive because agent *i*'s absolute wage as well as his wage relative to others is increasing in agent *i*'s outcome, and the functions v and ϕ are increasing. The second term in the integrand is positive by the CDFC condition in Assumption 4.

Finally, we show that the increase in envy reduces each agent's maximum expected utility. Suppose agents choose actions A' with higher envy. Then, agent *i*'s expected utility is

$$E[U_i']=\int_X\left\{v(w_i)+\gamma_H\sum_{j\in N-\{i\}}\phi(w_i-w_j)\right\}g(X,A')dX-c(a_i')$$
$$\le\int_X\left\{v(w_i)+\gamma_L\sum_{j\in N-\{i\}}\phi(w_i-w_j)\right\}g(X,A')dX-c(a_i')$$
$$\le\int_X\left\{v(w_i)+\gamma_L\sum_{j\in N-\{i\}}\phi(w_i-w_j)\right\}g(X,A)dX-c(a_i)$$
$$=E[U_i]\quad .$$

The first inequality holds because with identical agents, expected utility due to envy is negative, i.e., $\int_X\phi(w_i-w_j)g(X,A')dX<0$. This follows from Jensen's inequality as the expected relative wage is zero and the envy function is concave. The second inequality follows from the optimality of actions A when the envy parameter is γ_L. □

Proof of Proposition 4: By symmetry, agents will choose identical actions. Let a^* be the equilibrium action and $\hat{a}$ the action in collusion. Let $A^*\equiv(a^*,a^*)$ and $\hat{A}\equiv(\hat{a},\hat{a})$.

In equilibrium,

$$\frac{\partial}{\partial a_2}\left\{\int U_2(W(X),a_2)g(X,A)dX\right\}\Bigg|_{A=A^*}=0. \qquad \text{(A-9)}$$

Suppose $|v''/v'|\ge|\{\phi''(y)+\phi''(-y)\}/\phi'(y)|$. Then, by Proposition 2, we have

$$\frac{\partial}{\partial a_2}\left\{\int U_1\left(W(X),a_1\right)g(X,A)dX\right\}\Bigg|_{A=A^*} \leq 0 \quad . \tag{A-10}$$

Combining (A-9) and (A-10),

$$\frac{\partial}{\partial a_2}\left\{\sum_{j\in N}\int U_j\left(W(X),a_j\right)g(X,A)dX\right\}\Bigg|_{A=A^*} \leq 0. \tag{A-11}$$

However, when agents collude, we have

$$\frac{\partial}{\partial a_2}\left\{\sum_{j\in N}\int U_j\left(W(X),a_j\right)g(X,A)dX\right\}\Bigg|_{A=\hat{A}} = 0. \tag{A-12}$$

Comparing (A-11) and (A-12), $\hat{a} \leq a^*$. The proof for the second part of the proposition is similar. □

Proof of Proposition 5: Suppose ϕ is linear. Consider an optimal contract *W* and an optimal action set *A* with Lagrange multipliers α and β. With a marginal change in the envy parameter γ, the change in the principal's objective *Z* is given by

$$dZ/d\gamma + \alpha\frac{d}{d\gamma}\sum_i\int_X U_i\left(W(X),a_i\right)g(X,A)dX + \beta\frac{d}{d\gamma}\sum_i\int_X U_i\left(W(X),a_i\right)\frac{dg(X,A)}{da_i}dX$$
$$= 0 + \alpha(0) + \beta\sum_i\int_X\sum_{j\in N-\{i\}}\phi\left(w_i - w_j\right)\frac{dg(X,A)}{da_i}dX > 0$$

The last equality follows because the principal's objective is independent of γ and each agent's expected utility is independent of γ with identical agents and a linear envy function. The inequality follows from Chebyshev's inequality as in the proof of Proposition 3.

For the second part of the proposition, the marginal change in the principal's objective with a marginal change in envy is given by

$$dZ/d\gamma + \alpha\frac{d}{d\gamma}\sum_{i\in N}\int_X U_i\left(W(X),a_i\right)g(X,A)dX + \beta\frac{d}{d\gamma}\sum_{i\in N}\int_X U_i\left(W(X),a_i\right)\frac{dg(X,A)}{da_i}dX$$
$$= \sum_{i\in N}\int_X\sum_{j\in N-\{i\}}\phi\left(w_i - w_j\right)\left(\alpha g(X,A) + \beta\frac{dg(X,A)}{da_i}\right)dX$$
$$= \sum_{i\in N}\int_X\sum_{j\in N-\{i\}}\frac{\phi\left(w_i - w_j\right)}{v'(w_i) + \gamma\sum_{k\in N-\{i\}}\left\{\phi'(w_i - w_k) - \phi'(w_k - w_i)\right\}}g(X,A)dX \quad .$$

For small γ and linear v, this reduces to

$$\frac{1}{v'}\sum_{i\in N}\int_X\sum_{j\in N-\{i\}}\phi\left(w_i - w_j\right)g(X,A)dX < 0 \quad .$$

where the inequality follows from the symmetry of agents and the concavity of the function ϕ . □

Proof of Proposition 6: By differentiating expressions for Q and R, the following partial derivative signs are obtained:

$$\frac{\partial Q}{\partial k} > 0, \frac{\partial Q}{\partial l} < 0, \frac{\partial Q}{\partial \gamma} < 0, \frac{\partial R}{\partial k} < 0, \frac{\partial R}{\partial l} > 0, \frac{\partial R}{\partial \gamma} > 0 . \tag{A-13}$$

Further,

$$\frac{\partial Q}{\partial k}\frac{\partial R}{\partial \gamma} - \frac{\partial Q}{\partial \gamma}\frac{\partial R}{\partial k} > 0 . \tag{A-14}$$

The above expression is obtained by expanding partial derivatives and then applying Chebyshev's inequality as in the proof of Proposition 3. If the optimal contract is perturbed by decreasing expected wage *k* while changing *l* so that (IC) constraint (16) continues to hold, expected utility of agents in (15) must decrease below their reservation level. Thus, we must have

$$\frac{\partial Q / \partial k}{\partial R / \partial k} \leq \frac{\partial Q / \partial l}{\partial R / \partial l} < 0 .$$

which yields

$$\frac{\partial Q}{\partial k}\frac{\partial R}{\partial l} - \frac{\partial Q}{\partial l}\frac{\partial R}{\partial k} \geq 0 . \tag{A-15}$$

Totally differentiating (14) and (15) with respect to γ, we get

$$\frac{\partial Q}{\partial \gamma} + \frac{\partial Q}{\partial k}\frac{\partial k}{\partial \gamma} + \frac{\partial Q}{\partial l}\frac{\partial l}{\partial \gamma} = 0 , \tag{A-16}$$

$$\frac{\partial R}{\partial \gamma} + \frac{\partial R}{\partial k}\frac{\partial k}{\partial \gamma} + \frac{\partial R}{\partial l}\frac{\partial l}{\partial \gamma} = 0 . \tag{A-17}$$

Solving (A-16) and (A-17), we get,

$$\frac{\partial l}{\partial \gamma} = \frac{\frac{\partial Q}{\partial \gamma}\frac{\partial R}{\partial k} - \frac{\partial R}{\partial \gamma}\frac{\partial Q}{\partial k}}{\frac{\partial R}{\partial l}\frac{\partial Q}{\partial k} - \frac{\partial Q}{\partial l}\frac{\partial R}{\partial k}} < 0. \tag{A-18}$$

The inequality follows from (A-14) and (A-15). □

Proof of Proposition 7: The Kuhn-Tucker conditions for the minimization of (7) subject to constraints (5) and (8) with Lagrange multipliers $\alpha_i \geq 0$ and β_i are:

$$\left[\alpha_i\left\{v'(w_i)+\sum_{j\in N-\{i\}}\gamma_{ij}\phi'(w_i-w_j)\right\}-\sum_{j\in N-\{i\}}\gamma_{ji}\alpha_j\phi'(w_j-w_i)\right]$$
$$+\left[\beta_i\left\{v'(w_i)+\sum_{j\in N-\{i\}}\gamma_{ij}\phi'(w_i-w_j)\right\}-\sum_{j\in N-\{i\}}\gamma_{ji}\beta_j\phi'(w_j-w_i)\right]\frac{dg(x_i,a_i)\big/da_i}{g(x_i,a_i)} \tag{A-19}$$
$$=1 \qquad \forall i\in N.$$

Fix X and $l\in N$. Differentiating (A-19) with respect to x_l, we get,

$$\alpha_i v''(w_i)\frac{dw_i}{dx_l}+\sum_{j\in N-\{i\}}\gamma_{ij}\left\{\alpha_i\phi''(w_i-w_j)+\alpha_j\phi''(w_j-w_i)\right\}\left(\frac{dw_i}{dx_l}-\frac{dw_j}{dx_l}\right) \tag{A-20}$$
$$=0 \quad \forall i\in N-\{l\}.$$

First, we show by contradiction that $\frac{dw_l}{dx_l}\geq\frac{dw_i}{dx_l}$ for all i. If this is not true, then there exists a k such that and $\frac{dw_k}{dx_l}\geq\frac{dw_i}{dx_l}$ for all i and $\frac{dw_k}{dx_l}>\frac{dw_l}{dx_l}$. Substituting k for i in (A-20) yields $\frac{dw_k}{dx_l}\leq 0$ which implies $\frac{dw_i}{dx_l}\leq 0$ for all i.

Further, we must have $\frac{dw_l}{dx_l}\leq\frac{dw_i}{dx_l}$ for all i. If not, there must be a k such that and $\frac{dw_k}{dx_l}\leq\frac{dw_i}{dx_l}\leq 0$ for all i and $\frac{dw_k}{dx_l}<\frac{dw_l}{dx_l}\leq 0$ but the left-hand-side of (A-20) will be positive when evaluated for i = k. Thus, $\frac{dw_l}{dx_l}\leq\frac{dw_i}{dx_l}\leq 0$ for all i and the utility of agent l is non-increasing in his outcome. Such a contract cannot implement any action $a_l>-\infty$ so the supposition is contradicted and $\frac{dw_l}{dx_l}\geq\frac{dw_i}{dx_l}$ for all i.

Now, substituting $k\in\arg\min_{i\in N}\frac{dw_i(X)}{dx_l}$ for i in (A-20) yields $\frac{dw_k}{dx_l}\geq 0$ which implies $\frac{dw_i}{dx_l}\geq 0$ for all i.

Now, we show that agent i's wage will be independent in the outcome of agent j if and only if all agents can be partitioned into two groups such that the two agent belong to different groups and no agent from one group envies an agent from another group. For the *if* part suppose the two groups are P and Q such that agent i belongs to group P, agent j belongs to group Q and agents in one group do not envy agents in the other group. Consider a feasible wage contract W that bases wage of agents in group P on the outcomes of agents in group Q. It can be replaced by a wage contract W' such that

$$E\left[U_k\left(W_P'(X_P)\right)\right]=E\left[U_k\left(W_P(X)\right)\right] \quad \forall X,k\in P$$

where subscript P on a set indicates a subset restricted to agents in P. The wage contract W' implements the same actions as the contract W with lower expected wages because of the concavity of utility functions.

For the *only if* part, suppose wage contract W is such that wage of agent i is independent of outcome of agent j. Choose a set of outcomes X. Let P be the set of all agents whose wages are independent of small variations in agent j's outcome at X and let Q be the set of remaining agents. Substituting an agent k in P for i and agent j in Q for l in (A-20), we get

$$\sum_{m\in Q}\gamma_{km}\{\alpha_k\phi''(w_k-w_m)+\alpha_m\phi''(w_m-w_k)\}\frac{dw_m}{dx_j}=0 \quad \forall k\in P. \tag{A-21}$$

Since $dw_m/dx_j>0$, this implies $\gamma_{km}=0$ for all $k\in P, m\in Q$. □

Proof of Lemma 4: Consider $B^H>B^L$ and $w^H>w^L$. From (22),

$$\frac{\psi'\left(B^H\middle|W_{-i},w_i=w^H\right)}{\psi'\left(B^L\middle|W_{-i},w_i=w^H\right)}=\frac{\psi\left(B^H\right)}{\psi\left(B^L\right)}\times\frac{\prod_{j\neq i}k\left(w_j+B^H,\alpha^*\right)}{\prod_{j\neq i}k\left(w_j+B^L,\alpha^*\right)}\times\frac{k\left(w^H+B^H,\alpha^*\right)}{k\left(w^H+B^L,\alpha^*\right)}$$

$$>\frac{\psi\left(B^H\right)}{\psi\left(B^L\right)}\times\frac{\prod_{j\neq i}k\left(w_j+B^H,\alpha^*\right)}{\prod_{j\neq i}k\left(w_j+B^L,\alpha^*\right)}\times\frac{k\left(w^L+B^H,\alpha^*\right)}{k\left(w^L+B^L,\alpha^*\right)}=\frac{\psi'\left(B^H\middle|W_{-i},w_i=w^L\right)}{\psi'\left(B^L\middle|W_{-i},w_i=w^L\right)}$$

The inequality obtains because $k(c+\delta)/k(c)$ is a decreasing function of c for $\delta>0$ and log-concave k. Finally, the monotone likelihood ratio property implies first-order stochastic dominance. □

Proof of Proposition 8: From (23), the outsider assesses the likelihood ratio of abilities θ_H and $\theta_L<\theta_H$ as

$$\frac{g'\left(\theta_i=\theta^H\right)}{g'\left(\theta_i=\theta^L\right)}=\frac{h\left(\theta^H\right)\int_{-\infty}^{\infty}g\left(w^{-1}(w_i+B),\alpha^*,\theta^H\right)\psi'(B)dB}{h\left(\theta^L\right)\int_{-\infty}^{\infty}g\left(w^{-1}(w_i+B),\alpha^*,\theta^L\right)\psi'(B)dB} \tag{A-22}$$

The ratio $g\left(w^{-1}(w_i+B),\alpha^*,\theta^H\right)/g\left(w^{-1}(w_i+B),\alpha^*,\theta^L\right)$ is increasing in B because of the monotone likelihood ratio property. Thus, the likelihood ratio in (A-22) increases and the inferred mean ability from g' increases as the posterior density ψ' moves right in the first-order-stochastic-dominance sense. Combining this with Assumption 5 yields the result. □

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