The rise of individual performance pay*

Ola Kvaløy[†] and Trond E. Olsen[‡]

April 28, 2011

Abstract

Existing empirical evidence suggests that individual performance pay is more prevalent in human capital intensive industries. We introduce a model that can contribute to explain this. In a repeated game model of relational contracting, we analyze the conditions for implementing peer-dependent incentive regimes when agents possess indispensable human capital. We show that the larger the share of values that the agents can hold-up, the lower is the implementable degree of peer-dependent incentives. In a setting with complementary tasks, we show that while team-based incentives are optimal if agents are dispensable, it may be costly, and in fact suboptimal, to provide team incentives when the agents become indispensable.

JEL Classification: D23, J33, L14

Keywords: relational contracts; multiagent moral hazard; human capital, hold-up

1 Introduction

Firm value is increasingly dependent on human capital. The share of physical capital in publicly traded corporations has dramatically decreased since

*We thank two referees and Derek Clark, Bob Gibbons, Hideshi Itoh, Hideo Owan, Jack Stecher, and seminar participants at the Hitotsubashi University, Erasmus University, the MIT Sloan School of Management, the EIASM Workshop in Accounting and Economics, the CESifo Conference on Employment and Social Protection, the Conference of the European Association of Labour Economists, and the Congress of the European Economic Association for helpful comments.

[†]University of Stavanger, 4036 Stavanger, Norway. E-mail: ola.kvaloy@uis.no

[‡]Norwegian School of Economics and Business Administration, Helleveien 30, 5045 Bergen, Norway. trond.olsen@nhh.no

the 1970s, (see e.g. Blair and Kochan, 2000). At the same time we observe a higher degree of individual performance pay in modern corporations (see e.g., Brown et al., 1998; Brown and Heywood, 2002, and Lemieux et al., 2009). Are these trends related? Several studies indicate so. Long and Shields (2005), Lemieux et al. (2009) and Henneberger et al. (2007) find that individual performance pay is more likely to be found in firms with highly educated employees. A recent study by Barth et al. (2008) shows that the frequency of group-based incentives is decreasing for those with higher education, and increasing for blue-collar workers; while individual performance pay is found to be strongly associated with firms with a highly educated workforce.[1] Group-based incentive schemes (as in partnerships) are still quite common in certain high-skilled professional service industries such as law, accounting, investment banking and consulting, but researchers have noted that there is a trend away from equal sharing partnerships towards productivity-based "eat what you kill" partnerships (Levin and Tadelis, 2005).[2]

One explanation for the increased use of individual performance pay is that advances in information and communication technology have made it easier to measure individual performance (Lemieux et al., 2009). A question then is whether it has become relatively more easy to assess the performance of high-skilled workers. There is apparently no evidence that this is the case, and in fact, MacLeod and Parent (1999) find that incomplete incentive contracts based on looser performance assessments are associated with complex jobs. Barth et al. (2008) suggest that one should expect a positive relationship between human capital and individual performance pay because the quality and effort of high-skilled workers have larger impacts on productivity than the quality and effort of other groups of workers. They lend support from Brown (1990) who argues that in high-skilled jobs, worker output is more sensitive to worker quality than in jobs requiring lower skills. Henneberger et al. (2007) show that high-skilled workers tend to self-select

[1] Long and Shields (2005) and Barth et al.(2008) have the most detailed data on the likelihood of *individual* performance pay. They show that if the share of the workforce with a college degree increases with 1% point, the share of workers on individual performance pay schemes increases with 0,18% and 0,24% point in Canada and Norway, respectively. There is about 20% lower probability of having individual performance pay plans if you are a worker in a firm where no-one has a degree compared to a firm where everybody has a degree. For the U.S., Lemieux et al. (2009) show that the average years of schooling is about one year longer for those who work in performance pay jobs compared to those who work on fixed salaries only.

[2] In addition to the evidence mentioned, several studies show that firms with low union coverage are more willing to use individualized incentive schemes (see e.g. Brown, 1990; Parent, 2002, Long and Shields, 2005, Lemieux et al. 2009), and union coverage is lower among high-skilled workers (Acemoglu et al. 2001).

into jobs with performance pay, supporting Lazear's (1986) model. Along the same line, studies by Kato (2002) and Torrington (1993) show that workers with more education are particularly interested in receiving rewards tailored to individual performance.

In our view, these are plausible explanations. However, there are some remaining puzzles. Individualized incentives are not desirable when teamwork is important, or when it is difficult to verify each worker's contribution to firm value, but it is hard to see that this applies less to high-skilled than to low-skilled workers. In fact, several scholars in human resource management have argued that knowledge intensive organizations' emphasis on innovation, teamwork and projects calls for incentives that are group-based rather than based on individual performance (see e.g. Balkin and Bannister, 1993). We should thus look for an explanation saying that group-based incentives are desirable, but not feasible. Focusing on firms' inability to fully commit to incentive contracts, the literature has pointed out that group-based incentive schemes are harder to implement – and thus less feasible – than schemes based on relative performance evaluation (Carmichael, 1983; Malcomson, 1984; Levin, 2002, Kvaløy and Olsen, 2006). In this paper we focus instead on the workers' lack of ability to commit to incentive contracts, which we believe is a central feature of human capital intensive firms, and show that this feature makes individual performance pay easier to implement than most peer-dependent schemes.

We recognize here two features of human capital that - as we will argue below- necessitate a high degree of individual performance pay. First, the true performance of high-skilled workers is often difficult to verify by third parties. Incentives based on subjective performance evaluation are therefore typically used for more complex jobs where comprehensive objective measures are difficult to specify and/or measure (MacLeod and Parent, 1999). Consequently, incentive contracts specifying criteria for performance pay are seldom perfectly enforceable by the court. This enforcement problem also applies to low-skilled workers, but as noted above, incomplete incentive contracts are more common in the high-skilled workforce. Second, human capital blurs the allocation of ownership rights. According to the standard view of ownership, it is the owner of an asset who has residual control rights; that is "the right to decide all usages of the asset in any way not inconsistent with a prior contract, custom or law" (Hart, 1995). If the critical asset involved in the worker's production is his own mind and knowledge, it may thus be complicated to decide whether it is the employer or worker who has residual control rights. An indispensable "knowledge worker" can therefore threaten to walk away with ideas, clients, techniques, etcetera. As noted by Liebeskind (2000), human-capital-intensive firms must induce their employees to stay around long enough so that the firm can establish some intellectual property rights with respect to the ideas generated by these employees, or else these firms run the risk of being expropriated or held-up by their own employees.

Why do these two features - incomplete contracts and indispensable human capital - prepare the way for individual performance pay? In other words: Why is it difficult to implement *peer-dependent incentives* when performance is unverifiable and workers possess residual control rights? The answer is intuitive when we think of the incentives facing an agent who is a full residual claimant. He simply gets the values he has produced; the market incentives are not linked to what other agents produce. Hence, if a principal wants to implement a peer-dependent incentive contract, she faces a problem if her agents have residual control rights. With relative performance evaluation (RPE) an agent is not paid well if his peer performs better, while with team incentives - or joint performance evaluation (JPE) - he is not paid well if his peer's performance is poor. This peer-dependence may lead to contract breach: an agent who is paid a low bonus after realizing a high output has incentives to hold-up his output and renegotiate payments. Of course, a hold-up strategy is only possible if the agent actually is able to prevent the principal from realizing the agent's value added ex post production. But if hold-up *is* possible, then RPE and JPE schemes are more susceptible to hold-up than incentive schemes based on independent performance evaluation (IPE). [3]

The parties can mitigate the hold-up problem through repeated interaction, i.e. through self-enforcing relational contracting where contract breach is punished, not by the court, but by the parties who can refuse to cooperate after a deviation.[4] But since a hold-up will be regarded as a deviation from such a relational contract, the self-enforcing range of the contract is limited by the hold-up problem. And since the hold-up problem is most severe under joint or relative performance evaluation, we can expect a larger fraction of independent performance pay when hold-up is feasible for the agents.

Is this a problem? Yes, from the informativeness principle (Holmström, 1979, 1982) we know that an incentive contract should be based on all vari-

[3]Our argument bears some similarities to Oyer (2004), who shows that it may be optimal to let pay vary with the agent's outside option. But he focuses on the costs of adjusting incentive contracts and does not discuss the problem of implementing peer-dependent relational incentive contracts.

[4]Influential models of relational contracts include Klein and Leffler (1981), Shapiro and Stiglitz (1984), Bull (1987), MacLeod and Malcomson (1989), Baker, Gibbons and Murphy (1994, 2002) and Levin (2003). There is also a growing body of empirical work on relational contracting, see in particular Ryall and Sampson (2009).

ables that provide information about the agents' actions. Stochastic and/or technological dependences between the agents then typically call for peer-dependent incentive schemes. By tying compensation to an agent's relative performance, the principal can filter out common noise so that compensation is based more on real effort, and less on random shocks that are outside the agent's control (see Holmström, 1982; and Mookherjee, 1984).[5] And by tying compensation to the joint performance of a team of agents, the principal can exploit complementarities between the agents' efforts.[6]

Hence, from the informativeness principle it is puzzling that we actually observe incentive schemes based on independent performance evaluation. The drawbacks of team incentives and relative performance evaluation can partly explain why: Team incentives may be susceptible to free-riding (see e.g. Alchian and Demsetz, 1972; and Holmström, 1982), while RPE is susceptible to collusion (see e.g. Mookherjee, 1984). RPE may also induce sabotage and discourage cooperation (see Lazear, 1995, for a discussion of the costs and benefits of RPE and team incentives).

In this paper we provide a new argument for independent performance evaluation; an argument that is not based on these classical drawbacks, but rather on the implementability of peer-dependent incentives. Our main result then says that the maximum dependence between agent i's bonus and agent j's output that the principal can implement, decreases with the share of values that the agents can hold-up ex post.

With respect to team effects we consider the case of complementary tasks. We find that the optimal implementable scheme becomes less based on team incentives and more based on individual performance pay the larger the share of values the agents can hold-up. We also show that if agents differ in effort productivity and/or inherent ability, the most productive agent is - for a given hold-up power - given more individualized incentives than the less productive agent. Moreover, the effect of a higher hold-up power is stronger for the high-ability agent than for the low-ability agent. We argue that this result may contribute to our understanding of why performance pay increases wage inequality.

Broadly speaking, our contribution is to consider the effect of residual

[5] See also Lazear and Rosen (1981), Nalebuff and Stiglitz (1983) and Green and Stokey (1983) for analyses of RPE's special form, rank-order tournaments.

[6] In addition, JPE can promote cooperation since an agent is rewarded if his peers perform well (see e.g. Holmström and Milgrom, 1990; Itoh 1993; and Macho-Stadler and Perez-Castrillo, 1993). JPE can also provide implicit incentives not to shirk (or exert low effort), since shirking may have social costs (as in Kandel and Lazear, 1992), or induce other agents to shirk, which again reduces the shirking agent's expected compensation (as in Che and Yoo, 2001).

control rights in a multiagent moral hazard model. In the vast literature on multiagent moral hazard, it is (implicitly) assumed that residual control rights are exclusively in the hands of the principal. And in the literature dealing with optimal allocation of control rights, the multiagent moral hazard problem is scantily considered. [7]

Our basic set-up with two agents, binary effort and binary output, is similar to Che and Yoo (2001). As shown by these authors, peer monitoring is a rationale for making use of peer-dependent incentives such as JPE. We introduce and explore instead technological complementarities in this setting. And more importantly, we extend and complement their analysis by assuming non-verifiable output, and that agents are able to hold-up values ex post.[8]

The paper proceeds as follows. In Section 2 we present the model and deduce the optimal incentive contract. In Section 3 we study how variations in complementarity between the agents' tasks, and differences between the agents' productivity and ability levels affect incentive design. Section 4 offers some concluding remarks.

2 The Model

Consider an economic environment consisting of one principal and two agents ($i = a, b$) who each period produce either high, Q_H, or low, Q_L, values for the principal. Each agent's effort level can be either high or low, where high effort (e_1) has a disutility cost of c^i and low effort (e_0) is costless. The principal can only observe the realization of the agents' output, not the level of effort they choose. Similarly, agent i can only observe agent j's output ($i \neq j$, $j = a, b$), not his effort level.[9] Moreover, we assume that output is non-verifiable to a third party. Hence, contracts on output cannot be enforced by the court.

The agents' outputs are stochastically independent, and each agent's success probability depends on the agent's own as well as his peer's effort. Let $q^i(e^i, e^j)$ denote this probability, where $e^i \in \{e_0, e_1\}$ and $e^j \in \{e_0, e_1\}$ refer

[7] This literature begins with Grossman and Hart (1986) and Hart and More (1990), who analyze static relationships. Repeated relationships are analyzed in particular by Halonen (2002) and Baker, Gibbons and Murphy (2002). Although Hart and Moore (1990) analyze a model with many agents, they do not consider the classical moral hazard problem that we address, where a principal can only observe a noisy measure of the agents' effort.

[8] Kvaløy and Olsen (2008a) consider a model on cooperation (help) between agents with hold-up power, while Kvaløy and Olsen (2008b) endogenize the agent's hold-up power in a simpler model with no team effects.

[9] Whether or not the agents can observe each other's effort level is not decisive for the analysis presented. However, by assuming that effort is unobservable among the agents, we do not need to model repeated peer-monitoring.

to the agent's own and his peer's effort, respectively. To model technological complementarity between the agents' tasks, we assume that there are three levels of the success probability for each agent:[10]

$$\begin{aligned} q^i(e_1, e_1) &= q_1^i \\ q^i(e_1, e_0) &= q_{10}^i \\ q^i(e_0, e_1) &= q^i(e_0, e_0) = q_0^i, \quad \text{where } q_0^i \le q_{10}^i \le q_1^i, \;\; q_0^i < q_1^i. \end{aligned} \tag{1}$$

The idea here is that the peer's effort has a positive effect when the agent's own effort is high, but has no effect when own effort is low. Note also that $q_{10}^i = q_1^i$ corresponds to no team effects (independent technology), while $q_{10}^i = q_0^i$ corresponds to perfect complementarity; in the sense that slacking by one agent leads to low success probability for both agents, even if the other agent exerts high effort.

Throughout the paper we assume that the value of high effort exceeds its cost, in the sense that

$$\Delta q^i \Delta Q > c^i, \tag{2}$$

where $\Delta q^i = q_1^i - q_0^i$ and $\Delta Q = Q_H - Q_L$. It is moreover assumed that all parties are risk neutral, but that the agents are subject to limited liability: the principal cannot impose negative wages.[11] Ex ante reservation wages are assumed to be zero, for convenience.

The principal may offer each agent a wage contract saying that agent i receives a bonus $\beta^i \equiv (\beta_{HH}^i, \beta_{HL}^i, \beta_{LH}^i, \beta_{LL}^i)$ ex post value realizations, where the subscripts refer to agent i's and agent j's realizations of Q_k and Q_l, $(k, l = H, L)$, respectively. For each agent, a wage scheme exhibits joint (JPE), relative (RPE) or independent (IPE) performance evaluation if, respectively, $(\beta_{HH}, \beta_{LH}) > (\beta_{HL}, \beta_{LL})$,[12] $(\beta_{HH}, \beta_{LH}) < (\beta_{HL}, \beta_{LL})$, and $(\beta_{HH}, \beta_{LH}) = (\beta_{HL}, \beta_{LL})$. With JPE an agent is paid more if his peer does well, in RPE he is paid more if his peer does poorly, and in IPE his payment is independent of his peer's performance. Since outputs are not verifiable, a contract must be self-enforcing to be sustainable. We now describe the contracting environment in more detail.

[10]The model can be generalized to account also for stochastic dependence in the form of positively correlated outputs. As is well known, such dependence favors RPE relative to JPE and IPE, but it can be shown that all our results go through as long as the degree of this dependence is not too high.

[11]Limited liability may arise from liquidity constraints or from laws that prohibit firms from extracting payments from workers.

[12]The inequality means weak inequality of each component and strict inequality for at least one component. So a JPE scheme has $\beta_{HH} \ge \beta_{HL}$ and $\beta_{LH} \ge \beta_{LL}$ with at least one inequality being strict.

Each period the principal and the agents face the following contracting situation.

1. The principal offers a contract saying that agent i receives a bonus $\beta^i \equiv (\beta^i_{HH}, \beta^i_{HL}, \beta^i_{LH}, \beta^i_{LL})$ conditional on outputs as described above.

2. The agents simultaneously choose efforts. Provided the contract is honored, agent $i = a, b$ then gets an expected wage

$$\begin{aligned} \pi^i(e^i, e^j, \boldsymbol{\beta}^i) \equiv\ & q^i q^j \beta^i_{HH} + q^i(1-q^j)\beta^i_{HL} \\ & +(1-q^i)q^j\beta^i_{LH} + (1-q^i)(1-q^j)\beta^i_{LL} \end{aligned} \tag{3}$$

where the success probabilities depend on agent i's and agent j's efforts; e^i and e^j, respectively, so $q^i = q^i(e^i, e^j)$ and $q^j = q^j(e^j, e^i)$, with $e^i, e^j \in \{e_0, e_1\}$.

3. The agents' value realizations, Q_k and Q_l, $(k, l = H, L)$, are revealed.

4. The principal decides whether or not to honor the contract. If the principal reneges on the contract by refusing to pay β^i, she bargains with the agent and pays a spot price s^i for the good.

5. If the principal honors the contract, the agent chooses whether or not to deliver the good and accept the payment β^i. If he accepts, trade takes place according to the contract. If not, he bargains with the principal and obtains a spot price s^i.

The timing of events is summarized in Figure 1.

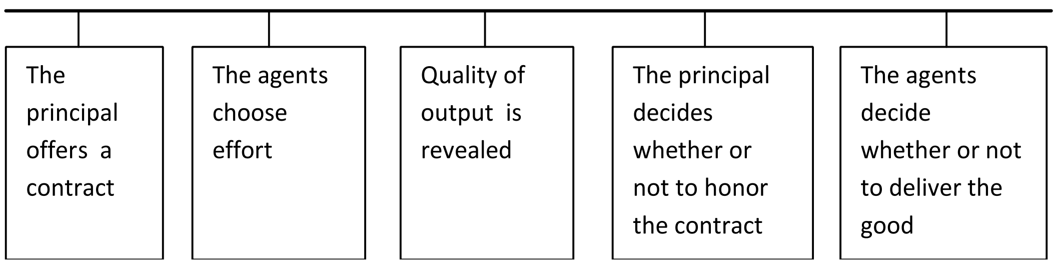

Figure 1: Timeline

While the three first stages are standard ingredients in principal-agent relationships, the fourth stage is also standard in incomplete contracting models where the principal has discretion over her choice whether or not to actually pay the promised bonus. The last stage is less standard. Usually it is assumed that values accrue directly to the principal in the process of production, but we assume that agents are able to hold-up values if they are not satisfied with the principal's offer in the fourth stage. This kind of modelling is common in bilateral buyer-supplier relationships, but not in multiagent relationships as presented here.

Now if stage 4 or 5 ends up in spot bargaining, we assume that the spot price is determined by Nash bargaining. In stage 4 agent i is able to independently attain $\theta^i Q_k$, $\theta^i \in [0,1]$ in an alternative market. In Nash bargaining, agent i will then receive $\theta^i Q_k$ plus a share γ^i of the surplus from trade i.e. .the spot price will be $s_k^i = \theta^i Q_k + \gamma^i (Q_k - \theta^i Q_k) = \eta^i Q_k$ where $\eta^i = \gamma^i + \theta(1 - \gamma^i)$. The parameter η^i can be interpreted as an index of the agent's total hold-up power. As we will see, increased hold-up power to agents does not reduce total surplus in our model. Rather, it increases the agents' rent and reduces the principal's flexibility when designing incentives.

An agent's hold-up power (η^i) is here an increasing function of ex post bargaining power (γ^i) and ex post outside options, (θ^i). The outside option parameter depends on the specificity of the agent's value-added. The more firm specific value-added – or the more narrow the agent's skill set – the lower is θ^i. But, importantly, note that even if $\theta^i = 0$, the agent can still achieve a share $\eta^i = \gamma^i$ ex post. This share γ^i of the surplus from trade is determined by ex post bargaining power, and will typically increase with the indispensability of the agent: If an agent possesses essential human capital that makes him indispensable for ex post value extraction, then γ^i is high. But if values accrue directly to the principal in the process of production, then the agents have no hold-up power: $\gamma^i = \theta^i = 0$, so that $\eta^i = 0$. So to obtain a positive spot price, the agents must be able to hold up values in stage 3.

The model allows us to study the effects of variations in hold-up power and differences in productivity and ability between the agents. While the levels of the success probabilities q_1^i and q_0^i are related to the inherent ability or talent of the agents, the ratio $\Delta q^i / c^i$ is a measure of the agents' effort productivity. High-skilled workers will typically have higher $\Delta q^i / c$, higher q_1^i, q_0^i and higher η^i. We will analyze how variations in these parameters affect incentive design. When analyzing differences in productivity and ability, we assume that the hold-up power is the same for both agents (and thus suppress superscripts on η). This makes it easier to distinguish the effects of variations in hold-up power from the effects generated by differences in effort productivity and ability.

Before proceeding, it should be noted that we consider a stationary model where the environment (technology) does not depend on the output obtained in previous periods. Hence, high performance in one period does not affect the future performance of the firm. Moreover, we do not analyze the incentives to invest in firm-specific human capital (as in e.g. Kessler and Lülfesmann, 2006). Rather, we just assume that agents become indispensable in the process of production (as in e.g. Halonen, 2002). We thus follow the relational contracting literature, and abstract from human capital accumulation.

The magnitudes of θQ_k and ηQ_k are therefore assumed to be exogenously given and constant each period. This simplifies the analysis and highlights the stationary effect of ex post hold-up power on the principal's incentive design.

2.1 The spot contract

A spot contract is a perfect public equilibrium (PPE)[13] of the contracting game described above. In stage 4, agent i will renege if his promised bonus for the given outputs is lower than the spot price ($\beta^i_{kl} < s_k$), and honor otherwise. In stage 4, the principal will renege if $\beta^i_{kl} > s_k$, and honor otherwise. Hence, at least one party will renege, unless $\beta^i_{kl} = s_k$. The only payment that can be implemented for agent i when he has output Q_k is thus $s_k = \eta Q_k$. Anticipating this, agent i will in stage 2 exert low effort if the cost of high effort exceeds the higher expected spot price induced by this effort, i.e. if $c^i > (q^i(e_1, e^j) - q^i((e_0, e^j))\, \eta \Delta Q$. Recalling our assumptions (1) we see that low effort is thus a strictly dominant strategy if

$$\Delta q^i \eta \Delta Q < c^i \tag{4}$$

Hence, we see that the spot contracting game has a unique continuation equilibrium from stage 2 if (4) holds. Each agent then exerts low effort and receives the expected spot price $S^i = \eta(Q_L + q^i_0 \Delta Q)$.

In our simple model, a contract to motivate high effort is only necessary if the parameters satisfy (4), since if not, the agents' hold-up power provides them with sufficient incentives. Hence, throughout the paper we assume that (4) holds, so that the principal has to implement an incentive contract in order to induce high effort. Since outputs are non-verifiable, the parties must rely on self-enforcing (relational) incentive contracts. An important reason for why a contract can be self-enforcing is that the parties incur reputational costs if they renege on the contract. The contract is honored if these costs are sufficiently high. Such reputational costs can be measured by the loss of future surplus. Modeling self-enforcing relational contracts as a repeated game provides us with a rigorous tool for analyzing the trade-off between short term gains and long-term losses from contract deviations. The repeated game approach is particularly relevant in employment relationships, which are typically repeated in nature.

[13] In a PPE each player's strategy is based on public information (not on privately observed efforts) and the strategies constitute at each stage a Nash equilibrium for the remainder of the game.

2.2 Relational contracts

Now, for the principal to implement high effort through a contract, the contract must be incentive compatible (IC) and self-enforcing, where a self-enforcing (relational) contract is a perfect public equilibrium of the infinitely repeated game in which the stage game described above is played every period.

We consider first the IC constraint. Focusing on stationary contracts, an implementable incentive scheme, β, is incentive compatible if[14]

$$\pi^i(e_1, e_1, \beta^i) - c^i \geq \pi^i(e_0, e_1, \beta^i), \quad i = 1, 2 \tag{5}$$

The left hand side (LHS) shows the expected wage minus the cost from exerting high effort, while the right hand side (RHS) shows the expected wage from exerting low effort. The condition (5) ensures that high effort from both agents is an equilibrium, given the contract β. The agents' equilibrium is unique for the given contract if high effort is a dominant strategy, i.e. if $\pi^i(e_1, e_0, \beta^i) - c^i \geq \pi^i(e_0, e_0, \beta^i)$ holds in addition to (5). The optimal wage schemes we deduce in this paper will ensure either such a unique high-effort equilibrium, or a high-effort equilibrium that is not Pareto dominated by a low-effort equilibrium.[15]

Consider now the conditions for the incentive contract to be self-enforcing, i.e. the conditions for implementing a *relational incentive contract*. The relational incentive contract is self-enforcing if all parties honor the contract for all possible values of Q_k and Q_l, $k, l \in \{L, H\}$. There are many possible self-enforcing contracts, but we focus here on trigger strategy equilibria in which the parties enter into spot contracting forever after one party reneges (as in e.g. Baker, Gibbons and Murphy, 2002; and Levin, 2002). We consider a multilateral punishment structure where any deviation by the principal triggers low effort from both agents. The principal honors the contract only if both agents honored the contract in the previous period. The agents honor the contract only if the principal honored the contract with both agents in

[14] We consider only stationary contracts, which are not restrictive when parties are risk neutral and there is no limited liability (Levin, 2003). When parties have limited liability, stationary contracts are not necessarily optimal. Fong and Li (2009) show, however, that under limited liability the optimal contract reaches a stationary equilibrium after a "probation phase".

[15] One can show that there is a threshold for the degree of complementarity such that for high complementarity there is a low-effort equilibrium, while for low complementarity there is no low-effort equilibrium. Moreover, an agent's payoff in the low-effort equilibrium is strictly smaller than his payoff in the high-effort equilibrium, except under perfect complementarity, where the payoffs are equal.

the previous period. Thus, if the principal reneges on the relational contract, both agents insist on spot contracting forever after. And vice versa: if one (or both) of the agents renege, the principal insists on spot contracting forever after. A natural explanation for this is that the agents interpret a unilateral contract breach (i.e. the principal deviates from the contract with only one of the agents) as evidence that the principal is not trustworthy (see Bewley, 1999, Levin, 2002).[16]

Now, (given that (5) holds) the principal will honor the contract if, for all realizations of output Q_k, Q_l, $k, l \in \{H, L\}$, by agents a and b, respectively, we have

$$\begin{aligned} & -\beta^a_{kl} - \beta^b_{lk} + \frac{\delta}{1-\delta}\sum_i \left[Q_L + q^i_1 \Delta Q - \pi^i(e_1, e_1, \beta^i)\right] \\ \geq \ & -\eta(Q_l + Q_k) + \frac{\delta}{1-\delta}\sum_i \left[Q_L + q^i_0 \Delta Q - S^i\right], \end{aligned} \tag{EP}$$

where δ is a common discount factor. The LHS of the inequality shows the principal's expected present value from honoring the contract, which involves paying out the promised bonuses and then receiving the value associated with high effort in all future periods. The RHS shows the expected present value from reneging, which involves spot trading of the realized outputs, and then receiving the value associated with low effort and spot trading in all future periods.

Agent i will honor the contract if

$$\beta^i_{kl} + \frac{\delta}{1-\delta}(\pi^i(e_1, e_1, \beta^i) - c^i) \geq \eta Q_k + \frac{\delta}{1-\delta} S^i, \qquad \textit{all } k, l \in \{H, L\} \tag{EA}$$

where similarly the LHS shows the agent's expected present value from honoring the contract, while the RHS shows the expected present value from reneging.

2.3 Optimal incentives

Given high effort from both agents, the principal's wage cost for agent i is

$$\pi^i(e_1, e_1, \beta^i) = q^i_1 \left[q^j_1 \beta^i_{HH} + (1 - q^j_1)\beta^i_{HL}\right] + (1 - q^i_1)\left[q^j_1 \beta^i_{LH} + (1 - q^j_1)\beta^i_{LL}\right] \tag{7}$$

[16] Modelling multilateral punishments is also done for convenience. Bilateral punishments will not alter our results qualitatively (see also Schottner, 2008, for a discussion of multilateral punishments in a relational contracting model with two agents and several tasks).

If one agent deviates from high to low effort, his own success probability will be reduced from q_1^i to q_0^i and his partner's from q_1^j to q_{10}^j. The IC condition (5) for high effort $\pi^i(e_1, e_1\beta^i) - c \geqslant \pi^i(e_0, e_1, \beta^i)$ can then be written as

$$\begin{aligned} & q_1^i \left[q_1^j \beta_{HH}^i + (1-q_1^j)\beta_{HL}^i\right] + (1-q_1^i)\left[q_1^j \beta_{LH}^i + (1-q_1^j)\beta_{LL}^i\right] - c^i \\ \geq \;& q_0^i \left[q_{10}^j \beta_{HH}^i + (1-q_{10}^j)\beta_{HL}^i\right] + (1-q_0^i)\left[q_{10}^j \beta_{LH}^i + (1-q_{10}^j)\beta_{LL}^i\right] \text{ (IC)} \end{aligned}$$

The optimal contract minimizes the total wage costs $\sum_i \pi^i(e_1, e_1, \beta^i)$, subject to the constraints given by limited liability, incentive compatibility (IC), and enforceability (EP and EA).[17]

As a reference case and to build intuition, consider first the case of verifiable outputs, for which the enforceability constraints are not relevant. The costs per agent can then be minimized separately. It is intuitive that an agent will not be paid a bonus for low output and hence that $\beta_{LL}^i = \beta_{LH}^i = 0$. Given this, we can see from IC and (7) that costs can be reduced by reducing β_{HL}^i and increasing β_{HH}^i so that IC is just satisfied (see (16) and the ensuing paragraph in the appendix). This implies that costs are minimal when also $\beta_{HL}^i = 0$, and hence that each agent is optimally paid a bonus only when both agents have high outputs ($\beta_{HH}^i > 0$). The minimal such bonus that yields sufficient incentives for high effort is found from IC, and we see that it is given by:

$$\beta_{HH}^i(q, c^i) = \frac{c^i}{q_1^i q_1^j - q_0^i q_{10}^j}$$

The associated minimal wage cost for agent i is then from (7) seen to be $\pi_V^i(q, c^i) = \beta_{HH}^i(q, c^i) q_1^i q_1^j$, i.e.

$$\pi_V^i(q, c^i) = \frac{q_1^i q_1^j}{q_1^i q_1^j - q_0^i q_{10}^j} c^i \tag{8}$$

Comparing this contract to a contract with independent evaluation ($\beta_{HH}^i = \beta_{HL}^i \equiv \beta_H^i$), we see from IC that the latter can implement high effort with a bonus $\beta_H^i = c^i/\Delta q^i$. But since this bonus is paid every time the agent has high output, it yields higher costs than the JPE scheme, which pays a bonus only when both agents have high output ($q_1^i c^i/\Delta q^i > q_1^i q_1^j \beta_{HH}^i(q, c^i)$). The intuition is that when tasks are complements, low effort from agent i yields a negative externality on agent j. With joint performance evaluation the agent is punished for this, i.e. JPE internalizes the externality to some extent. This makes it less costly to implement high effort under JPE than

[17] These constraints also ensure that all parties are at least as well off with the relational contract as with a spot contract.

under independent or relative performance evaluation.

The optimal incentive scheme for verifiable output is thus a scheme with a very stark form of joint performance evaluation and a high degree of peer dependence, in that agents are only paid bonuses if both of them realize high outputs. We will now see that for *non-verifiable outputs*, the enforceability constraints associated with relational contracts, and in particular the degree of agent hold-up reflected in those constraints, can severely modify the optimal incentive scheme and lead to considerably less peer dependence.

For non-verifiable outputs, the principal will minimize total wage costs subject to limited liability, incentive and enforceability constraints. It is instructive to first analyze this problem without taking account of the enforceability constraint for the principal, and then check this constraint ex post. In this procedure the costs per agent can be minimized separately, since the relevant constraints pertaining to one agent do not involve the incentive scheme for the other agent. To state the result, recall our maintained assumption that spot incentives are insufficient for high effort; see (4), which can equivalently be expressed as

$$\eta < \eta_0 = \min_i \{ \frac{c^i}{\Delta q^i \Delta Q} \}.$$

We then have the following:

Proposition 1 *Provided Q_L is not too small, then for η above some threshold ($\eta_1 < \eta < \eta_0$) the incentive scheme that minimizes costs subject to incentive and enforceability constraints for the agents (IC and EA) has the following features:*
i) Each agent is paid a fixed salary ($\beta^i_{LH} = \beta^i_{LL}$) plus a bonus increment for high output ($\beta^i_{Hk} - \beta^i_{Lk}$). The bonus increment exceeds the spot reward increment for high output ($\beta^i_{Hk} - \beta^i_{Lk} \geq \eta \Delta Q$), is peer dependent, and is of the joint performance evaluation (JPE) type ($\beta^i_{HH} > \beta^i_{HL}$).
ii) The enforceability constraints EA are binding for all bonuses except β^i_{HH}, and the bonuses satisfy (9-10) below.
iii) As the hold-up parameter η increases, the degree of peer dependence ($\beta^i_{HH} - \beta^i_{HL}$) decreases.
iv) Each agent's fixed salary component (β^i_{Lk}) and the minimal wage cost for the principal are increasing in the hold-up parameter η and decreasing in the discount factor δ. The minimal wage cost exceeds the cost $\pi^i_V(q, c^i)$ associated

with verifiable output.

$$\beta^i_{LH} = \beta^i_{LL} = \beta^i_{HL} - \eta \Delta Q \quad (9)$$
$$\beta^i_{HH} = \beta^i_{HL} + \frac{1}{q^i_1 q^j_1 - q^i_0 q^j_{10}} \left[c^i - \eta \Delta q^i \Delta Q\right] \quad (10)$$

The main message from the proposition is that if contracts are not enforceable by the court and the agents have hold-up power, then they cannot commit to stay in a relational contract with strong team incentives. If agent i has produced Q_H while his peer has produced Q_L, then the contract entitles him to β^i_{HL}, while he can achieve ηQ_H by renegotiating with the principal. Hence, for a relational incentive contract to be sustainable, the bonus β^i_{HL} must be high if η is high. This is reflected in (10), which clearly shows that the bonus increment $\beta^i_{HH} - \beta^i_{HL}$ is smaller, the larger is the agent's hold-up power η. For symmetric agents we also see that in the limit, as the hold-up power becomes sufficiently high ($\eta \to \frac{c^i}{\Delta q^i \Delta Q}$), only individual performance pay (where $\beta^i_{HH} = \beta^i_{HL}$) becomes feasible. Hence, ex post bargaining power and/or outside options do not only increase the agents' rents (as is well know from the literature), but also change the form of compensation towards more individualized incentives. This result contributes to explaining why individual performance pay is more common in human capital intensive industries, where agent hold-up is an important issue.

So far we have ignored the dynamic enforceability constraint for the principal (EP). To be fully feasible a contract must also satisfy this constraint. It is straightforward to show (proof available from the authors) that the scheme in Proposition 1 is implementable (satisfies the principal's enforceability constraint EP) if the discount factor δ exceeds a threshold $\underline{\delta}(\eta) < 1$. The larger the hold-up parameter η (for $\eta < \eta_0$), the smaller this threshold is, and hence the easier it is to implement the relational contract. This follows intuitively from the fact that a higher η reduces the principal's gain from deviating from the contract. A higher η is not socially disadvantageous here since it is the agents and not the principal, who exert effort in this model. Hold-up power incentivizes the agents, but limits the form of compensation that the principal can use.

3 Complementarity, heterogeneity and incentives

We will now study in more detail how incentive design is affected by variations in the degree of complementarity between the agents' production technologies, and by differences between the agents' productivity and/or ability levels.

When analyzing the effects of differences between the agents (heterogeneity) we will keep the level of complementarity constant. If there is no complementarity between the agents, the analysis of heterogeneity becomes less interesting, as individual performance pay is then always (weakly) optimal. Similarly, when studying variations in complementarity, we will keep the level of heterogeneity constant, and for expositional simplicity we will then consider identical agents.

3.1 Incentives for heterogenous agents

We start by studying the effects of differences between the agents. Consider first differences in effort productivity, and suppose agent i is more productive in this respect (so $\frac{c^i}{\Delta q^i} < \frac{c^j}{\Delta q^j}$). Then we see from (10) that if the hold-up power becomes sufficiently large ($\eta \to \frac{c^i}{\Delta q^i \Delta Q} = \eta_0$), agent i's incentives will become independent of his partner's performance ($\beta^i_{HH} = \beta^i_{HL}$), while the incentives of the other agent will remain peer dependent. Thus we have:

Proposition 2 *As the hold-up parameter η increases, the degree of peer dependence ($\beta^i_{HH} - \beta^i_{HL}$) decreases, but not at the same rate for the two agents. As η gets large ($\eta \to \eta_0$) the incentive scheme for the most productive agent (with $\frac{c^i}{\Delta q^i} < \frac{c^j}{\Delta q^j}$) approaches a scheme with independent performance evaluation (IPE), while the scheme for the other agent remains JPE.*

Thus we see that if agents differ with respect to effort productivity, the most productive agent - for a given hold-up power η - is given more individualized incentives than the agent with low effort productivity, even if their hold-up powers are equal. In the limit (as η gets large, $\eta \to \eta_0$) the less productive agent is offered a bonus that depends on the performance of the most productive agent, but where the reverse is not true. This contributes to explaining why lower-level employees are often given team incentives based on the firm's overall performance, while those at higher levels are offered individual performance pay (see e.g. Barth et al. 2008 and Mohn et al., 2010).

We also find that the effect of a higher hold-up power on the expected wage depends on the agents' abilities**.** For simplicity, we here assume perfect complementarity ($q^i_{10} = q^i_0$). It then turns out that the marginal effect of higher hold-up power on the expected wage ($\frac{\partial \pi^i}{\partial \eta}(e_1, e_1)$) is largest for agent

i if

$$\delta(\Delta q^i - \Delta q^j) + (\frac{q_1^i}{q_0^j}\Delta q^j - \frac{q_1^j}{q_0^i}\Delta q^i) > 0 \tag{11}$$

(See the appendix.) For given effort costs and effort productivities, the LHS in (11) increases in both q_1^i and q_0^i while it decreases in q_0^j and in q_1^j. Hence, higher hold-up power increases the wage difference between high- and low-ability workers. This result contributes to our understanding of why performance pay increases wage inequality. Lemieux et al. (2009) show that wages are less equally distributed in performance pay jobs because the return to productive characteristics is higher in such jobs. Our result suggests that increased hold-up power to agents may reinforce this tendency.

As we will now explain, the main results in Propositions 1 and 2 can be illustrated by a simple figure. Given that each agent is paid a fixed salary for low output (independent of the other agent's output, $\beta^i_{LH} = \beta^i_{LL}$), and this salary is set as low as permitted by the enforceability constraints for these wage payments, we see from (EA) that the corresponding constraints for the payments associated with high output take the form

$$\beta^i_{Hk} - \eta\Delta Q \geq \beta^i_{LH} = \beta^i_{LL}, \qquad k = H, L \tag{EA'}$$

This relation says that the bonus increments for high output $\beta^i_{HH} - \beta^i_{LH}$ and $\beta^i_{HL} - \beta^i_{LL}$ must both exceed $\eta\Delta Q$, which is the additional value of high output for the agent outside the relationship. These relations are represented by the lines marked EA' in Figure 2. Only bonuses in the northeast region delineated by this L-shaped curve satisfy the enforceability constraints for the agent. Bonus schemes with independent performance evaluation are represented by points on the diagonal line (IPE), and those with joint (relative) performance evaluation by points above (below) that line.

To be incentive compatible with high effort, bonuses must satisfy IC, and this can here be represented by points above a line such as IC^i in the figure.[18] Moreover, it is straightforward to verify that an isocost curve for the wage cost $\pi^i(e_1, e_1, \beta^i)$ will be represented by a line which is more steeply sloped than IC^i, as indicated by the dashed line in the figure. Given these facts, it is clear that the bonus scheme that minimizes costs subject to EA and IC will be at the intersection point between EA' and IC^i above the diagonal in the figure. This point represents a scheme with joint performance evaluation. The agent is then paid a bonus increment for high output ($\beta^i_{Hk} - \beta^i_{Lk}$) that depends on the other agent's output, and is larger when the latter is high

[18] The IC constraint is linear in the bonuses, and can be expressed in terms of the bonus increments when $\beta^i_{LH} = \beta^i_{LL}$.

($k = H$) than when it is low ($k = L$). The bonus increment strictly exceeds the value of high output for the agent outside the relationship (i.e. the EA constraint is not binding) only when the other agent's output is also high.

As the hold-up parameter η increases, the EA constraints become tighter, and the EA' lines shift northeast in the figure, as indicated by the arrow. This implies that the solution point for the optimal scheme moves downwards on the IC^i line towards the diagonal, i.e. towards a scheme with independent performance evaluation. The vertical distance from the solution point along EA' to the diagonal is given by $\beta^i_{HH} - \beta^i_{HL}$ and is thus a measure of the extent to which agent i's bonus for high output depends on the other agent's output. This can be taken as a measure of peer dependence in the bonus scheme, and we see that this dependence decreases as the hold-up parameter η increases.

Two identical agents would have identical IC lines and hence identical bonus schemes. In the limit as η approaches η_0, this common scheme would become an IPE scheme (on the diagonal) and thus have no peer dependence. By definition of η_0 it is the case that for symmetric agents and $\eta \geq \eta_0$ the spot contract provides sufficient incentives for high effort. This contract has no peer dependence, and for η approaching η_0 (from below) we see that the relational contract then cannot have such dependence in the limit either.

Heterogenous agents will have separate IC lines, as illustrated by IC^i and IC^j in the figure. Here agent i is most productive, in the sense of having the smallest cost per unit probability increase induced by high effort, i.e. $\frac{c^i}{\Delta q^i} < \frac{c^j}{\Delta q^j}$. Geometrically the IC line for agent i then intersects the diagonal closer to the origin (at bonus increments equal to $\frac{c^i}{\Delta q^i}$). As the hold up parameter then increases towards η_0, we see that the optimal scheme for agent i approaches an IPE scheme, while the scheme for the least productive agent j remains JPE.

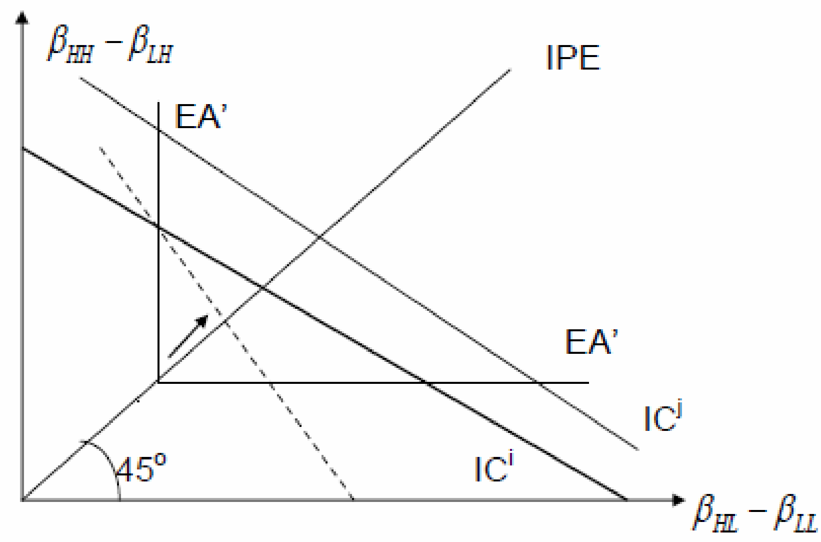

Figure 2: Illustration for Proposition 1

3.2 Complementarity and incentives

To study variations in complementarity, represented by variations in the parameter q^i_{10}, we consider for expositional simplicity identical agents. Recall that (dropping superscripts) q_{10} is the probability of obtaining high output for a hard working agent, given that his partner shirks. The partner's impact is larger, the smaller is q_{10}, all else equal. A higher level of complementarity between the agents is thus represented by a reduction of q_{10}.

First, it should be noted that the insight from Proposition 1 that the degree of peer-dependence decreases with higher hold-up power η is robust to variations in the degree of complementarity. In addition we have the following:

Proposition 3 *i) The degree of peer dependence ($\beta_{HH} - \beta_{HL}$) decreases with more complementarity (reduced q_{10}). This effect is smaller (in absolute value), the larger the hold up parameter η is.*
ii) The minimal wage cost decreases with more complementarity.

Even though complementarity makes it optimal for the principal to offer a JPE scheme, we see that higher complementarity does not lead to a starker scheme; in fact it is the other way around: Under team incentives, higher complementarity incentivizes the agents because each agent's effort improves his peer's output. Higher complementarity thus reduces the team bonus increment $\beta_{HH} - \beta_{HL}$ necessary to implement high effort. The empirical implication is that the degree of peer dependence in the incentive scheme should not be expected to increase with the degree of technological interdependence between the agents.

These results can be illustrated by Figure 3, which is similar to Figure 2. For given parameters there is here one common IC line for the two (identical) agents. For verifiable outputs, where there are no enforceability constraints, the optimal contract is then a stark JPE contract, represented by point J in the figure.

For the relational contract, the enforceability constraints for the agents (represented again by EA') clearly force the optimal contract to be less extreme. The optimal contract is still JPE (represented by the intersection point between IC and EA' above the diagonal), but it moves towards an IPE contract as the hold up parameter η increases.

Regarding variations in the degree of complementarity, as measured by the probability q_{10}, it can be seen that a higher q_{10} will rotate the IC line clockwise around its intersection point with the diagonal. A higher degree of complementarity (a lower q_{10}) will lead the IC line to rotate as indicated in Figure 3, i.e. to a less steep line (IC'). As explained above, this will relax implementation of JPE contracts, and the figure illustrates how this implies that the optimal contract will have a lower degree of peer-dependence. (The optimal point shifts down along EA'.) It also illustrates that this effect is smaller the larger the hold-up parameter η is.

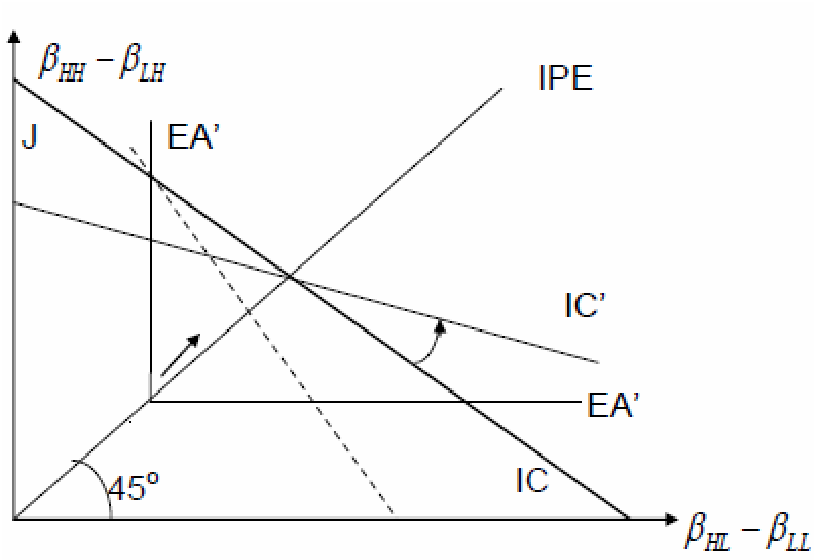

Figure 3: Illustration for Proposition 2

We finally note that, if the agents' production technologies are independent, i.e. if $q_{10} = q_1$, then the IC line will be parallell to an isocost curve. Since any point on IC will then yield minimal costs, we see that a scheme with independent performance evaluation (i.e. on the diagonal) will be optimal in that case.

4 Concluding remarks

There is still limited theoretical research on the relationship between human capital and incentive provision. Our approach has been to consider the effect of employee hold-up in a setting with multiple (two) agents, but the model can be extended in various ways. We have not considered dynamic effects of investments in human capital, nor the kind of hold-up problem that appears when firms' incentives to invest in their workers' human capital are mitigated by the workers' ability to capture the return from these investments (by e.g. exploiting outside options). Our model can also be generalized further to more agents ($n > 2$) and possible bilateral contracting with different groups of agents (as in Levin 2002). And it can be extended to account not only for technological dependence, but also for stochastic dependence between the agents, or social dependence such as peer pressure.[19]

[19] To model peer pressure in this framework, we may assume that there are costs associated with lowering the peer's wage by realizing low output, i.e. that the agents experience

Nevertheless, we believe our model can elucidate some important recent developments. In an interesting review of the history of employment relationships, Peter Cappelli (2000) argues that the last twenty years have seen a dramatic shift from traditional bureaucratic employment structures to "inside contracting systems (...) shaped by individualized incentives and pressures from outside labor markets". Along the same lines, Levin and Tadelis (2005) argue that greater competition in the labour market and changes in market information have made it less valuable to commit to the profit sharing plans of professional partnerships.

We offer a model that helps explain this rise of individual performance pay. We have shown that compensation tied to peer performance can induce employee hold-up and obstruct the implementation of relational incentive contracts. The model presented can thus explain the tendency to use individual performance pay in human-capital-intensive industries. Tremblay and Chenevert (2005) and Appelbaum (1991) note that even if knowledge-based industries are characterized by teamwork, the challenge to retain the most critical resources increases the pertinence of rewarding individual performance. Our model supports this conjecture.

APPENDIX

Proof of Proposition 1. The proposition follows from the lemma below.[20]

Lemma 1 *There is* $\underline{Q}_L > 0$ *such that for* $Q_L > \underline{Q}_L$ *the following holds. There is* $\eta_1 < \eta_0 = \min\{\frac{c^i}{\Delta q^i \Delta Q}\}$ *such that for* $\eta \in (\eta_1, \eta_0)$ *the incentive scheme that minimizes costs subject to incentive and enforceability constraints for the agents (IC and EA) has the following features:*
i) The EA constraints are binding for all bonuses except β^i_{HH}*, and the bonuses are given by (9-10) in the text and (13) below.*
ii) The minimal wage cost for agent i *is*

$$\pi^i(e_1, e_1) = \pi^i_V(q, c^i) + q^i_0 q^i_1 \frac{q^j_1 - q^j_{10}}{q^i_1 q^j_1 - q^i_0 q^j_{10}} \eta \Delta Q + \beta^i_{LL} \quad (12)$$

disutility from being the "weakest link". In an extended version of the paper (available from the authors' upon request), we show that while peer pressure makes team incentives optimal when agents are dispensable, team incentives becomes suboptimal once the agents' enforcement constraints (EA) bind.

[20] To simplify notation we ignore β^i as an argument in $\pi^i()$ in what follows.

where $\pi_V^i(q, c^i)$ *is given by (8), and*

$$\beta_{LL}^i = \underline{\beta}^i(\eta, \delta, Q_L, q, c^i) = \eta Q_L - \delta\left[c^i - \left(q_1^i - q_0^i\right)\eta\Delta Q\right]\frac{q_0^i q_{10}^j}{q_1^i q_1^j - q_0^i q_{10}^j} \quad (13)$$

iii) The cost $\pi^i(e_1, e_1)$ *and the bonus* β_{LL}^i *are increasing in* η *and decreasing in* δ.

Proof of the lemma.

Write the IC constraint as

$$\begin{aligned} c^i \leq\ & \left(q_1^i q_1^j - q_0^i q_{10}^j\right)\beta_{HH}^i + \left(q_1^i(1-q_1^j) - q_0^i(1-q_{10}^j)\right)\beta_{HL}^i \quad (14)\\ & + \left((1-q_1^i)q_1^j - (1-q_0^i)q_{10}^j\right)\beta_{LH}^i + \left((1-q_1^i)(1-q_1^j) - (1-q_0^i)(1-q_{10}^j)\right)\beta_{LL}^i \end{aligned}$$

Define p_{kl}^i as the term multiplying β_{kl}^i in (14), i.e.

$$\begin{aligned} p_{HH}^i &= q_1^i q_1^j - q_0^i q_{10}^j > 0 \quad (15)\\ p_{HL}^i &= q_1^i(1-q_1^j) - q_0^i(1-q_{10}^j)\\ p_{LH}^i &= (1-q_1^i)q_1^j - (1-q_0^i)q_{10}^j\\ p_{LL}^i &= (1-q_1^i)(1-q_1^j) - (1-q_0^i)(1-q_{10}^j) < 0, \end{aligned}$$

where the inequalities follow from $q_{10}^j \in \left[q_0^j, q_1^j\right]$, and note that $\Sigma p_{kl}^i = 0$.

Now substituting for β_{HH}^i from (14) into the expression (7) for costs we obtain, after some algebra

$$\begin{aligned} \pi^i(e_1, e_1) \geq\ & \frac{q_1^i q_1^j}{p_{HH}^i}c^i + \left[q_0^i q_1^i \frac{q_1^j - q_{10}^j}{p_{HH}^i}\right]\beta_{HL}^i \quad (16)\\ & + \left[q_1^j q_{10}^j \frac{q_1^i - q_0^i}{p_{HH}^i}\right]\beta_{LH}^i + \left[(1-q_1^i)(1-q_1^j) - q_1^i q_1^j \frac{p_{LL}^i}{p_{HH}^i}\right]\beta_{LL}^i \end{aligned}$$

The terms multiplying $\beta_{HL}^i, \beta_{LH}^i$ and β_{LL}^i are positive, hence these bonuses should be minimal.

For verifiable output it would thus be optimal to set $\beta_{HL}^i = \beta_{LH}^i = \beta_{LL}^i = 0$, and the minimal cost would be $\pi_V^i(q, c^i) = q_1^i q_1^j c^i / p_{HH}^i$, which is precisely the cost given in (8).

For non-verifiable output, the EA constraints of the relational contract must be taken into account. Ignoring non-negativity constraints for the moment (these will be checked ex post), the minimal cost is then achieved when the EA constraints for the bonuses $\beta^i_{HL}, \beta^i_{LH}$ and β^i_{LL} are binding, and thus

$$\beta^i_{LH} = \beta^i_{LL} = \eta Q_L + \frac{\delta}{1-\delta}\left[S^i - \pi^i(e_1, e_1) + c^i\right] = \beta^i_{HL} - \eta\Delta Q \qquad (17)$$

where $S^i = \eta(Q_L + q^i_0 \Delta Q)$.

Substituting $\beta^i_{LH} = \beta^i_{HL} - \eta\Delta Q = \beta^i_{LL}$ into (16), which must then hold with equality, we find after some algebra that the RHS of (16) –and hence the minimal cost $\pi^i(e_1, e_1)$ – is given by the expression in (12).

Consider now the optimal bonus β^i_{LL}. The minimal cost π^i is given by (12), where the bonus β^i_{LL} satisfies (17). These conditions imply that the bonus β^i_{LL} must be given by the expression in (13). To see this, we can substitute for $\beta^i_{LL} = \eta Q_L + \frac{\delta}{1-\delta}\left[S^i - \pi^i(e_1, e_1) + c^i\right]$ from (17) into (12) and solve for $\pi^i(e_1, e_1)$ to obtain

$$\pi^i(e_1, e_1) = (1-\delta)\left(\pi^i_V + q^i_0 q^i_1 \frac{q^j_1 - q^j_{10}}{q^i_1 q^j_1 - q^i_0 q^j_{10}} \eta\Delta Q + \eta Q_L\right) + \delta\left[S^i + c^i\right] \quad (18)$$

where $S^i = \eta(Q_L + q^i_0 \Delta Q)$. Some algebra shows that this condition and (12) imply that the bonus β^i_{LL} must be given by the expression in (13).

It remains to check non-negativity for this solution for the bonus β^i_{LL}. Define η^i_1 as the value of η that makes the expression in (13) positive for all $\delta < 1$, ie let η^i_1 be given by $\underline{\beta}^i(\eta^i_1, 1, Q_L, q, c^i) = 0$. For $Q_L > 0$ we see that $\eta^i_1 < \frac{c^i}{(q^i_1 - q^i_0)\Delta Q} \equiv \eta^i_0$. Also, since η^i_1 is smaller, the larger is $Q_L > 0$, there is $\underline{Q}_L > 0$ such that for $Q_L > \underline{Q}_L$ we have $\max\{\eta^i_1, \eta^j_1\} \equiv \eta_1 < \min\{\eta^i_0, \eta^j_0\} \equiv \eta_0$. Since then $\underline{\beta}^i(\eta, \delta, Q_L, q, c^i) > 0$ for $\eta \in (\eta_1, \eta_0)$ and $\delta < 1$ it follows that β^i_{LL} in (13) is positive and hence optimal, and that the minimal cost is indeed given by (12).

From the binding EA constraints we have $\beta^i_{LH} = \beta^i_{LL} = \beta^i_{HL} - \eta\Delta Q$ (see (17)), and by the IC constraint (14) and the definitions (15), the optimal bonus β^i_{HH} is then given by

$$\begin{aligned}\beta^i_{HH} &= \frac{1}{p^i_{HH}}\left(c^i - p^i_{HL}\beta^i_{HL} - p^i_{LH}\beta^i_{LH} - p^i_{LL}\beta^i_{LL}\right) \\ &= \frac{1}{p^i_{HH}}\left(c^i + (p^i_{LH} + p^i_{LL})\eta\Delta Q\right) + \beta^i_{HL}\end{aligned}$$

where the last equality follows from $\Sigma p^i_{kl} = 0$. This verifies the expression (10) for β^i_{HH}, since $p^i_{LH} + p^i_{LL} = -(q^i_1 - q^i_0)$.

So far we have proved statements (i) and (ii) in the lemma. Statement

(iii) follows since it is clearly the case that $\underline{\beta}^i(\eta, \delta, Q_L, q, c^i)$ is increasing in η and decreasing in δ. This completes the proof.

Verification of (11)
With perfect complementarity ($q_{10}^k = q_0^k$), we have from (12-13)

$$\frac{\partial \pi^i}{\partial \eta}(e_1, e_1) = Q_L + \Delta Q \frac{q_0^i q_0^j}{q_1^i q_1^j - q_0^i q_{10}^j} \left(\frac{q_1^i}{q_0^j} \left(q_1^j - q_0^j \right) + \delta \Delta q^i \right)$$

We see that agent i has the steepest derivative if $\frac{q_1^i}{q_0^j} \Delta q^j + \delta \Delta q^i > \frac{q_1^j}{q_0^i} \Delta q^i + \delta \Delta q^j$, i.e. if (11) holds.

Proof of Proposition 3.
Statement (i) follows directly from the expression for the bonuses in (10). Differentiation of the expressions in (13) and (12) shows that $\partial \beta_{LL} / \partial q_{10} < 0$ and

$$\frac{\partial \pi}{\partial q_{10}} = \frac{q_0 q_1^2}{\left(q_1^2 - q_0 q_{10}\right)^2} \left[c - \left(q_1 - q_0\right) \eta \Delta Q \right] (1 - \delta) > 0 \tag{19}$$

This proves statement (ii) and completes the proof.

References

[1] Acemoglu, Daron, Philippe Aghion and Gianluca Violante. 2001. Deunionization, Technical Change and Inequality. *Carnegie-Rochester Conference Series on Public Policy.*

[2] Appelbaum, Steven H. 1991. Compensation strategy: Determinants and contingencies in high technology organizations. *International Journal of Manpower 12: 22-30.*

[3] Baker, George, Robert Gibbons and Kevin J. Murphy. 1994. Subjective performance measures in optimal incentive contracts. *Quarterly Journal of Economics* 109: 1125-56.

[4] ——. 2002. Relational contracts and the theory of the firm. *Quarterly Journal of Economics* 117: 39-94.

[5] Balkin, David B. and Brendan D. Bannister. 1993. Explaining pay form for strategic employee groups in organizations: A resource dependence perspective. *Journal of Occupational and Organizational Psychology* 66: 139-151.

[6] Barth, Erling, Bernt Bratsberg, Torbjørn Hægeland, Oddbjørn Raaum. 2008. Who Pays for Performance? *International Journal of Human Resources* 16: 1783-1811.

[7] Bewley, Truman. 1999. *Why Wages Don't Fall During a Recession.* Cambridge, MA: Harvard University Press.

[8] Blair, Margaret M. and Thomas A. Kochan. 2000. *The New Relationship. Human Capital in the American Corporation.* The Brooking Institution Press.

[9] Brown, Charles. 1990. Firm's choice of method of pay. *Industrial and Labor Relations Review* 43: 165-182.

[10] Brown, Michelle, and John S. Heywood. 2002. *Paying for performance: An international comparison.* Armonk NY: M.E. Sharpe.

[11] Brown, William, Simon Deakin, Maria Hudson, Cliff Prattor and Paul Ryan. 1998. The individualization of employment contracts in Britain. Department of Trade and Industry, University of Cambridge

[12] Bull, Clive. 1987. The existence of self-enforcing implicit contracts. *Quarterly Journal of Economics* 102: 147-59.

[13] Cappelli, Peter. 2000. Market-mediated employment: The Historical Context. In *The New Relationship. Human Capital in the American Corporation.* eds. Margaret M. Blair and Thomas A. Kochan. The Brooking Institution Press.

[14] Carmichael, H. Lorne. 1983. Firm specific human capital and promotion ladders. *Bell Journal of Economics* 14: 251-258.

[15] Che, Yeon-Koo, and Seung-Weon Yoo. 2001. Optimal incentives for teams. *American Economic Review* 91: 525-40.

[16] Fong, Yuk-fai and Jin Li. 2009. Relational Contracts, Limited Liability, and Employment Dynamics. Working paper, Kellogg School of Management.

[17] Green, Jerry R., and Nancy L. Stokey. 1983. A comparison of tournaments and contracts. *Journal of Political Economy* 91:349-64.

[18] Grossman, Sanford, and Oliver Hart. 1986. The costs and benefits of ownership: A theory of lateral and vertical integration. *Journal of Political Economy* 94: 691-719.

[19] Halonen, Maija. 2002. Reputation and allocation of ownership. *The Economic Journal* 112: 539-58.

[20] Hart, Oliver, and John Moore. 1990. Property rights and the nature of the firm. *Journal of Political Economy* 98: 1119 – 58.

[21] Henneberger, Fred, Alfonso Sousa Poza and Alexandre Ziegler. 2007. Performance Pay, Sorting, and Outsourcing. *IZA*, DP NO. 3019.

[22] Holmström, Bengt. 1979. Moral hazard and observability. *Bell Journal of Economics* 10: 74-91.

[23] Holmström, Bengt. 1982. Moral hazard in teams. *Bell Journal of Economics* 13: 324-40.

[24] Holmström, Bengt, and Paul Milgrom. 1990. Regulating trade among agents. *Journal of Institutional and Theoretical Economics* 146: 85-105.

[25] Itoh, Hideshi. 1993. Coalition incentives and risk sharing. *Journal of Economic Theory* 60: 410-27.

[26] Kandel, Eugene, and Edward P. Lazear. 1992. Peer pressure and partnerships. *Journal of Political Economy* 100: 801-817.

[27] Kato, Takao. 2002. Financial participation and pay for performance in Japan. In *Paying for performance: An international comparison.* eds. Michelle Brown and John S. Heywood. Armonk NY: M.E. Sharpe.

[28] Kessler, Anke, and Christoph Lülfesmann. 2006. The theory of human capital revisited: on the interaction of general and specific investments. *The Economic Journal* 116: 903-923.

[29] Klein, Benjamin, and Keith Leffler. 1981. The role of market forces in assuring contractual performance. *Journal of Political Economy* 89: 615-41.

[30] Kvaløy, Ola, and Trond E. Olsen. 2006. Team incentives in relational employment contracts. *Journal of Labor Economics* 24: 139-169.

[31] —— and ——. 2008a. Cooperation in Knowledge-Intensive Firms. *Journal of Human Capital* 2: 410-440.

[32] —— and ——. 2008b. Relative performance evaluation, hold-up and firm organization. *Journal of the Japanese and International Economies,* 22: 229-241.

[33] Lazear, Edward P. 1995. *Personnel Economics*. The MIT Press.

[34] Lazear, Edward P., and Sherwin Rosen. 1981. Rank-order tournaments as optimum labor contracts. *Journal of Political Economy* 89: 841-64.

[35] Lemieux, Thomas, W. Bentley Macleod and Daniel Parent. 2009. Performance Pay and Wage Inequality. *Quarterly Journal of Economics* 124: 1-49.

[36] Levin, Jonathan. 2002. Multilateral contracting and the employment relationship. *Quarterly Journal of Economics* 117: 1075-1103.

[37] ——. 2003. Relational incentive contracts. *American Economic Review* 93: 835-57.

[38] Levin, Jonathan and Steven Tadelis. 2005. Profit Sharing and Professional Parnerships, *Quarterly Journal of Economics*, 120: 131-172.

[39] Liebeskind, Julia Porter. 2000. Ownership, incentives, and control in new biotechnological firms. In *The New Relationship. Human Capital in the American Corporation*. eds. Margaret M. Blair and Thomas A. Kochan. The Brooking Institution Press.

[40] Long Richard J. and John L. Shields. 2005. Performance pay in Canadian and Australian firms: a comparative study. *International Journal of Human Resource Management* 16: 1783-1811.

[41] Murphy, Kevin J. 1999. Executive compensation. In *Handbook of Labor Economics, Vol. 3*. eds. Orley C. Ashenfelter and David Card, North Holland.

[42] Macho-Stadler, Ines, and J. David Perez-Catrillo. 1993. Moral hazard with several agents: The gains from cooperation. *International Journal of Industrial Organization* 11: 73-100.

[43] MacLeod, W. Bentley. 2003. Optimal contracting with subjective evaluation. *American Economic Review* 93: 216-240.

[44] MacLeod, W. Bentley, and James Malcomson. 1989. Implicit contracts, incentive compatibility, and Involuntary Unemployment. *Econometrica* 57: 447-80.

[45] MacLeod and Parent. 1999. Job charaterstics and the form of compensation. *Research in Labor Economics* 18, 177-242.

[46] Malcomson. James M. 1984. Work incentives, hierarchy and internal labor markets. *Journal of Political Economy* 92: 486-507.

[47] Mohn, Klaus, Ola Kvaløy and Arngrim Hunnes. 2009. Performance Appraisal and Career Opportunities: A Case Study. No 2009/11, UiS Working Papers in Economics and Finance, University of Stavanger.

[48] Mookherjee, Dilip. 1984. Optimal incentive schemes with many agents. *Review of Economic Studies* 51: 433-46.

[49] Nalebuff, Barry J., and Joseph E. Stiglitz. 1983. Prizes and incentives: Toward a general theory of compensation and competition. *Bell Journal of Economics* 14:21-43.

[50] Oyer, Paul. 2004. Why do firms use incentives that have no incentive effects? *The Journal of Finance* 59: 1619-1649.

[51] Rajan, Raghuram G. and Luigi Zingales. 2001. The firm as a dedicated hierarchy: A theory of the origins and growth of firms. *Quarterly Journal of Economics* 116: 805-852.

[52] Ryall, M.D. and R. C. Sampson. 2009. Formal contracts in the presence of relational enforcement mechanisms: Evidence from technology development projects. *Management Science:* 55: 906 - 925.

[53] Shapiro, Carl and Joseph E. Stiglitz. 1984. Equilibrium unemployment as a worker discipline device. *American Economic Review* 74: 433-44.

[54] Schottner, Anja. 2008. Relational contracts, multi-tasking, and job design. *Journal of Law, Economics, and Organization* 24: 138-162.

[55] Torrington, Derek. 1993. Sweets to the sweet: Performance related pay in Britain. *International Journal of Employment Studies* 1: 149–64.

[56] Tremblay, Michel and Denis Chenevert. 2005. The effectiveness of compensation strategies in international technology intensive firms. *International Journal of Technology Management* 31: 222–239.