Collective versus Relative Incentives: the Agency Perspective

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Abstract

What is the best way of providing incentives to a team of agents? Agency theory has given a number of answers in the past three decades on the choice between collective and relative incentive provision. We present a broad overview of this rich literature through a simple model. While the early contributions emphasize the role of performance comparison and competition in motivating agents, more recent research highlights on the contrary the value of organizing cooperation and accounts for a variety of peer-effects. We present some empirical and experimental findings when available, and point out some directions for future research.

JEL classification: D20, D86, J33, L23, M12, M50.

Keywords: Incentive contracts, moral hazard, teams, competition vs cooperation, free-riding, tournaments, peer-effects, organizational design.

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1 Introduction

What is the best way of inciting a group of agents toward productive effort? From organizational design to market design, at the firm level or society level, the issue of what is the best institutional framework for rewarding a 'good performance' is obviously overwhelming. The question we tackle here is: when should incentives be provided collectively, on a team basis, or relatively, thereby creating competition among the agents?

Creating competition and fostering cooperation are two alternative ways of creating incentives. It is common practice to compensate vendors on the basis of realized sales. It is also often the case that sales people are given additional incentives through awards of prizes such as for best vendor of the week, month or year. CEOs are given stock incentives, and oftentimes their performance is also assessed in comparison to how firms in the industry performed. Those forms of competition aim at boosting incentives. In other circumstances, such as movers working as a team (Alchian and Demsetz, 1972), individual contributions are much harder to disentangle and the use of collective bonuses becomes more appropriate. In the public sector, the issue of motivation is traditionally handled by the promotion system in which the decision is mostly based on the subjective assessment of a higher-level manager. In innovative startups, the hierarchical structure is very flat and most motivation flows from generalized stock participation. The use of yardstick competition among hospitals or electricity facilities contributes to providing incentives to their managers. At the same time, employees in a given service can be offered collective bonuses to foster cooperation and smooth information transmission. Each of those examples can be viewed as a principal-agent problem, in which the incentive scheme (and organizational design) is chosen according to a number of features of the economic environment.

Whereas (micro)economic concerns with such examples are so old that they are almost impossible to trace, incentive theory drastically changed the view of economists in the early 70's, when problems of asymmetric information where at introduced into formal models. This constituted an important step beyond the towering achievement of the team theory proposed by Marschak and Radner (1972), in which agents inside the organization were assumed to share a common goal. Introducing asymmetric information[1] and opportunistic agents opened a number of new questions, as raised in the celebrated paper of Alchian and Demsetz (1972). The literature on multiagent agency problems

[1] Groves (1973) introduced an general model of multiagent adverse selection in firms. For a comprehensive overview of the mechanism design approach to organizations, see Mookherjee (2006).

then really took off with tournaments being presented as an alternative to piece-rate incentives, and more generally treating competition as an incentivizing device (Lazear and Rosen, 1981)–a radically opposite view from the inherently cooperative approach of team theory. While collective bonuses were usually seen as inefficient given the moral-hazard-in-teams problem emphasized by Alchian and Demsetz (1972), Holmström (1982) found an elegant solution with the intervention of a budget-breaking principal. As new considerations were introduced, the literature has deepered its consideration of the role of collective incentives as a way to better internalize a variety of peer-effects, such as help and communication on the one hand, and sabotage and influence activities on the other. Agency theory provides a framework which allows the analyst to relate the characteristics of tasks (e.g. production technology and information structure) to the optimal way of providing incentives to a group of agents.[2] This review is organized around those different characteristics and organizational factors, which are all presented within a simple model that allows us to draw a full picture of the mapping from basic characteristics to optimal team incentives.

The approach followed here rests on a generic formulation of the principal multiagent framework, and while the results we gather apply very broadly, we are mostly interested in applications to organization theory. The principal can be thought of as representing the interest of the government in a policy-making framework, the shareholders of a firm in a corporate context, or even the manager of a nonprofit organization or public administration service. The agents can be respectively firms, divisions of a firm, or employees of a given corporate or government structure.

The approach is decidedly normative: agency theory determines what is the best way of providing incentives in a given well-specified model. It can nevertheless be relevant for a wide range of applied questions such as: making sense of diversity of observed incentive practices; explaining why some firms perform better than others in a given sector or identifying social phenomena in the workplace. Whenever possible, we point out empirical evidence (see e.g. Weiss, 1987; FitzRoy and Kraft, 1987, for early contributions) as well as experimental results: the issue of optimal team incentives has generated a large experimental literature in psychology and management, and more recently in economics (see e.g. Bull, Schotter and Weigelt, 1987; Nalbantian and Schotter, 1997, for wide-

[2] Social-psychologists have also been interested for a long time in this question. See Deutsch (1949*b*,*a*) for seminal contributions. It is obviously a key point for the management literature (see DeMatteo, Eby and Sundstrom (1998) for a review in organization studies and Cohen and Bailey (1997) in the management field) and the growing literature on personnel economics initiated by Lazear (1995)

ranging contributions). The mechanisms described here are analyzed in isolation, but many of them may be expected to be simultaneously at play in a real context. We hope that the analysis can serve as a road map and provide building blocks for future empirical and experimental approaches.

Section 2 presents the baseline model through which the analysis will be carried out. In section 3, we consider how basic interdependences of agent activities affect the nature of the optimal incentive scheme. We distinguish technological and informational interdependences: individual tasks are technologically interdependent when one agent's effort affects the other's marginal productivity. They are informationally interdependent when one agent's result provides information about the other agent's effort through some underlying correlation. Both kinds of interdependences can make agents' efforts either complements or substitutes calling for, cooperation or competition, respectively, as the optimal incentive device. We also highlight that other-regarding preferences are a source of interdependence and can constitute a reason for using a dependent scheme. Section 4 is devoted to the study of the link between organizational factors and incentive schemes. Organizational factors characterize the potential for agents to engage in collusive/coalitional behavior. In an organization where agents know each other, can communicate or even observe each others' actions the incentive scheme must account for the fact that agents can act cooperatively (e.g. collude against the principal or team up in the interest of the organization). This is shown to significantly drive the choice of the appropriate incentive device toward cooperative schemes. Section 5 considers limits on contracting, such as commitment and renegotiation issues. The problem of double-moral hazard is studied and shown to call for competitive incentives. In the same manner, the impossibility of commitment for the principal (generating a risk of hold-up on agents' efforts) makes competition more likely to be the optimal incentive device. On the other hand, dependent incentive schemes may fail when agents can walk away from the organization with part of the surplus, in which case independent schemes should then be preferred. Finally, we conclude by highlighting the key findings and point out some open theoretical and empirical research questions.

2 Framework

2.1 Basics

The core of the framework under study features two agents, whose identity is indicated by $i \in \{1,2\}$. All players are assumed to be risk-neutral, but we discuss the case of risk-averse agents when relevant.[3] It is also assumed for simplicity that the agents are symmetric, but the qualitative results are unchanged with asymmetric agents, and we discuss the case of asymmetric agents. As in Itoh (1991), Ramakrishnan and Thakor (1991), Che and Yoo (2001) and Fleckinger (2012), each agent i is in charge of one project, which (expected) value to the principal is an increasing function of the effort e_i expanded by the corresponding agent.[4] Moral hazard comes from the fact that effort is not directly observable, but instead the principal observes only a pair of signals (or results) (R_1, R_2), each signal being informative on at least one agent's choice of effort. This signal takes two values, high or low: H or L. These signals are the only contractible variables.[5] A generic result pair is denoted by $\boldsymbol{R}$, taking value in $\{HH, HL, LH, LL\}$. Each agent privately chooses whether he exerts effort or not: $e_i \in \{0,1\}$, at a cost $c.e_i$. The efforts are not observed by the other players, unless explicitly noted. The probability of obtaining outcome $\boldsymbol{R} \equiv (R_i, R_{-i})$ conditional on effort pair (e_i, e_{-i}) is $Prob(\boldsymbol{R}|e_i, e_{-i})$, with the usual notation $-i$ referring to "the other agent". Note that this formulation allows for any type of externality (through both information and technology) between the two agents. Importantly, we assume that the principal always seeks to induce both agents to work, so that moral hazard plays a role for both of the projects. If the efforts of the agents were observable and contractible, the principal would use forcing contracts to obtain the pair of efforts $(1,1)$. Such a contract requires each agent to exert effort, and compensates on the basis of the cost incurred, c. Hence each agent i would face a simple independent contract, with a transfer c, conditional on implementing $e_i = 1$. There is no need in the first-best world to make use of realized outcomes in the contract, nor to introduce dependent incentives between the agents.

[3]The moral hazard literature leans on two ways of making incentives costly: risk-averse agents or bounds on transfers, i.e. limited liability (see Laffont and Martimort, 2002, chapter 4). Due to its relative technical simplicity, we use limited liability in this paper. Moreover, we provide equivalent results that only existed in the risk aversion framework, and provide original results which would require much more tedious analysis in a framework with risk-averse agents. One should note that Bolton and Dewatripont (2005) contains a brief treatment of the problem under study here. While we seek to conduct our analysis in a unified model, their exposition relies instead on a variety of models, and the reader is referred to their chapter 8, in particular sections 8.1 and 8.2 for the case of risk-averse agents that we do not cover.

[4]For most of our results, we do need to model the principal's full payoff function: only the cost of providing incentives will matter. Whenever needed we will introduce explicitly the benefit part.

[5]There are two other equivalent interpretations for this setting: the actual realizations of V are too distant in the future (e.g. a firm's stream of profits over an infinite time horizon) to be contracted upon, hence only the intermediate signals are contractible, or the signals themselves can represent the realized outcomes, but those outcome depend on noise outside of control by the agents, hence they are not perfectly informative on efforts.

2.2 Incentive Schemes

When efforts are not observable, the principal bases the (optimal) incentive contract on realized performances. Since the performances of the agents are generally related, each wage should be made contingent on both outcomes. The incentive scheme (or wage profile) is thus a collection

$$\boldsymbol{w} = \{w_{HH}, w_{HL}, w_{LH}, w_{LL}\}$$

that represents the wage received, as a function of own result–the first index–and the second agent's result–the second index. The notation $w_{\boldsymbol{R}}$ will represent the element of the vector $\boldsymbol{w}$ when the outcome $\boldsymbol{R}$ occurs. Given an outcome-contingent wage scheme $\boldsymbol{w}$ and a pair of efforts (e_i, e_{-i}) (with the usual convention), agent i's expected payoffs are:

$$(1) \quad U_i(\boldsymbol{w}|e_i, e_{-i}) = \mathbb{E}_{\boldsymbol{R}}\left[w_{\boldsymbol{R}}|e_i, e_{-i}\right] - c(e_i)$$

The central question of the review we undertake is: under which circumstances is it better for the principal to use relative incentives, or on the contrary to use team bonuses? To give a precise formal meaning to this question, we adopt the following typology for the incentive systems:[6]

Definition 1. *(Standard incentive schemes)*
An incentive scheme exhibits ***Collective Performance Evaluation*** *(CPE) when:*

$$(w_{HH}, w_{LH}) > (w_{HL}, w_{LL})$$

An incentive scheme exhibits ***Relative Performance Evaluation*** *(RPE) when:*

$$(w_{HL}, w_{LL}) > (w_{HH}, w_{LH})$$

An incentive scheme exhibits ***Independent Performance Evaluation*** *(IPE) when:*

$$(w_{HH}, w_{LH}) = (w_{HL}, w_{LL})$$

where the inequalities represent component-wise comparison with at least one strict inequality. With RPE, an agent is better off when the other fails, while it is the converse with CPE. Therefore, RPE is competitive while CPE provides collective incentives.[7] Note that these three types of scheme do not exhaust the possible orderings of wages.

2.3 The principal's problem

As already mentioned, it is assumed that the principal wants both agent to exert effort. This amounts for the principal to minimizing the cost of implementing $(1, 1)$ as a Nash equilibrium. This is the problem the early literature has been concerned with. We treat other implementation solu-

[6] This is a slight variation on the typology used in Che and Yoo (2001), with "Collective performance evaluation" standing here for "Joint performance evaluation" in their paper.

[7] Indeed those CPE schemes foster cooperation between the agents. This aspect will be discussed further when we incorporate the possibility of help and sabotage.

tions (unique Nash and collusive behavior) in the next sections. Basic Nash implementation entails the following incentive constraints:

(2) $U_i(\boldsymbol{w}|1,1) \geq U_i(\boldsymbol{w}|0,1) \quad \text{for } i = 1,2$

Finally, the agents are subject to limited liability:

(3) $$\boldsymbol{w} \geq 0$$

The principal should also make sure that the agents prefer to participate, rather than obtaining some reservation utility $\overline{U}$ elsewhere in the economy. As is standard, we assume that the limited liability constraint is tighter than this participation constraint, and we henceforth ignore the latter.

It is easy to remark that the program of the principal is in fact separable in the incentive schemes. Indeed, the incentive constraint of each agent features only his own wage, while the cost of implementation is linear in the wages. Hence the principal's program takes the simple form:

$$\min_{w} \mathbb{E}_{\boldsymbol{R}} \left[w_{\boldsymbol{R}} | 1,1 \right]$$
$$\text{subject to (2), (3)}$$

Given the well known importance of likelihood ratios in moral hazard problems, we will use the following terminology in the following:

Definition 2. *For any pair of results* $\boldsymbol{R}$*, the **incentive efficiency** of* $w_{\boldsymbol{R}}$ *is:*

$$I(\boldsymbol{R}) \equiv 1 - \frac{1}{h(\boldsymbol{R})} = \frac{Prob(\boldsymbol{R}|1,1) - Prob(\boldsymbol{R}|0,1)}{Prob(\boldsymbol{R}|1,1)}$$

The incentive efficiency is the ratio between the coefficient of the wage $w_{\boldsymbol{R}}$ in the incentive constraint and the probability of paying this wage in equilibrium. This is therefore the ratio of marginal incentive to marginal cost for that wage, which explains the notion of incentive efficiency. Note that it is at most 1, in which case the wage is fully effective, since the result $\boldsymbol{R}$ then indicates with certainty that the agent has exerted effort.

In order to solve the principal's problem, the following lemma, though straightforward to prove, is very useful:

Lemma 1. *Under risk-neutrality and limited liability, an optimal incentive scheme entails positive wages only for the result(s) with the highest incentive efficiency.*

The lemma simply formalizes the intuitive idea that the incentive weight should be put on the outcomes that are most efficient at inducing effort, according to the previous definition. In what follows, this implies that an agent should then never be rewarded after a low result,[8] i.e. w_{LH} and w_{LL} will always be optimally set to 0. So, the principal's problem reduces to comparing the incentive efficiencies of w_{HH} and

[8] See Fleckinger (2012, section 4) for a complete discussion of this point.

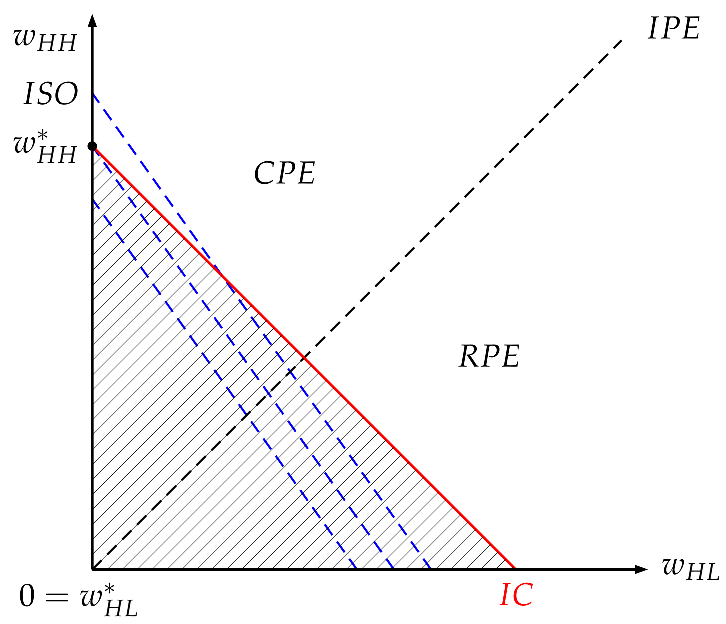

Figure 1: A Principal's Problem in which CPE is Optimal

w_{HL}. Figure 1 provides a convenient representation of this problem. The set of incentive compatible schemes is above the incentive constraint (IC). The optimal scheme is then determined by the intersection of the incentive constraint and the lowest isocost curve (ISO). Whether the optimal scheme is RPE or CPE depends on the comparison of the slopes of the incentive constraint and of the isocost curves, which is equivalent to comparing the incentive efficiencies of w_{HH} and w_{HL}. In the particular case where the incentive efficiencies of the two bonuses are equal, any incentive scheme binding the incentive constraint is optimal.

3 Basic Interdependencies

Dependent schemes are optimal if the incentive efficiencies of collective and relative bonuses differ, which is equivalent to saying that the agents' tasks are interdependent. This section presents two types of task interpendences, namely technological and informational interdependences.

3.1 Complementarity and team incentives

Consider two workers selling products in the same store. If they sell the same product then an increase in one agent's effort makes it more difficult for his collegue to perform well. On the other hand, if the two workers sell complementary products, good performance of one agent eases the job of his collegue. The technological externalities described in those examples ought to be accounted for in the incentive scheme by making an agent internalize the effect of his action on his peer's result. In order to highlight technological externalities in our model, we assume that production is *informationally independent*, i.e. :

$$(4)\quad Prob(R_i R_{-i}|e_i, e_{-i}) = Prob(R_i|e_i, e_{-i})Prob(R_{-i}|e_i, e_{-i})$$

In other words, R_i and R_{-i} are conditionally independent. Technological externalities are introduced using the notations

$$p_{e_i e_{-i}} \equiv Prob(R_i = H|e_i, e_{-i}).$$

The production exhibits positive externalities if $p_{11} > p_{10}$ in which case agents' efforts are complementary. Similarly, the production exhibits negative externalities if $p_{11} < p_{10}$ in which case agents' efforts are substitute. In the case where $p_{11} = p_{10}$ efforts are independent. The next result is an easy corollary of the first lemma:

Proposition 1. *When production is informationally independent, the optimal scheme exhibits CPE when efforts are complements, RPE when they are substitute, and IPE when they are independent.*

This proposition echoes an old idea in Marschak and Radner (1972) and Alchian and Demsetz (1972), who proposed that complementarities were what characterizes team production, the fundamental feature of organization.[9] Incentives in firms usually have at least some partial flavor of CPE. Tools such as stock-options, team and division bonuses, celebrations of goal achievements all share this joint feature. On the other hand, market competition is associated with substitute products, and competitive reward. To some extent, the normative result of the proposition echoes well with those broad principles of economic organization in market economies.

The optimal match between technology and incentives was a concern of the early developments of incentive theory in labor economics (e.g. Drago and Turnbull, 1987, 1988). In the field of managerial economics, a few papers have dealt with technological interdependence and contractual form (see for instance Choi, 1993). Technological externalities are also fundamental for job design in teams, as analyzed by Itoh (1994) and Lin (1997).

[9]"Team production [...] is production in which 1) several types of resources are used and 2) the product is not a sum of separable outputs of each cooperating resource" (Alchian and Demsetz, 1972, p. 779). Equivalently, Marschak and Radner (1972) refer to this as "labor input complementarity".

3.2 Correlation and the informativeness principle

While in the previous subsection we showed that (pure) technological links called for CPE or RPE, we neutralize here this channel, to concentrate on the cross inference aspect of multiagent incentive schemes. When the performances of different agents are correlated, a celebrated theorem by Holmström (1979), the ”sufficient statistics result”, or ”Informativeness Principle”, shows that the incentive schemes optimally uses this informational link in the design of incentives. This calls for peer-dependent assessment of the performance. Consider a police department that rewards its detectives based on the number of arrests they made over a year. All detectives' results are dependent on the unobserved level of criminality in the city. All agents performing well indicates that the environment was favorable and so does not call for high rewards. On the other hand, one agent performing well while his collegues do not indicates high effort and therefore calls for high bonus.

To focus exclusively on the informational dimension of the problem, we assume away 'technological' interaction, i.e. the effort of one agent does not influence the result of the other agent:

(5)

$$Prob(R_i|e_i, e_{-i}) = Prob(R_i|e_i) \quad \forall R_i, e_i, e_{-i}$$

We will be even more specific, in order to be in line with the literature, by considering the effect of the covariance of the results. Formally, in this binary outcome model, this amounts to consider a parameter γ such that, for any (R_i, R_{-i}):

$$Prob(R_i = R_{-i}|e_i, e_{-i}) = Prob(R_i|e_i)Prob(R_{-i}|e_{-i}) + \gamma$$

$$Prob(R_i \neq R_{-i}|e_i, e_{-i}) = Prob(R_i|e_i)Prob(R_{-i}|e_{-i}) - \gamma$$

Hence γ is a correlation parameter such that when it is higher, agents are more likely to obtain good results together (and bad results together). When dealing with technologically independent production, we shall use the notation

$$p_{e_i} \equiv Prob(R_i = H|e_i)$$

in the following. Hence one has for instance: $Prob(HL|e_i, e_{-i}) = p_{e_i}(1 - p_{e_{-i}}) - \gamma$. We are now in position to replicate the usual teaching of many traditional models: the optimal scheme should use comparison when performances are positively correlated.

Proposition 2. *When production is technologically independent, the optimal scheme exhibits RPE when $\gamma > 0$, CPE when $\gamma < 0$, and IPE when $\gamma = 0$.*

The intuition for this very anchored result is that using a RPE scheme allows to filter the common random component, and hence to better calibrate incentives, because the common "luck" due to elements outside of the agents' control has been corrected for. This central result leans on a fundamental result obtained by Holmström (1979), asserting that any informative signal should be used in the optimal contract. The formal statement relies on the concept of a sufficient statistics, and gives the precise conditions under which such an additional signal is valuable. With the present notation, this indicates that R_{-i} should be used in the contract of agent i if and only if R_i is not a sufficient statistics for $\boldsymbol{R}$. With technological independence, this is the case if and only if γ is different from zero. The use of this sufficient statistics result in (and its generalization to) multiagent models dates back to Holmström (1982) and Mookherjee (1984).[10] As illustrated in the next section, this has been also used in the literature on tournaments.

It is interesting to note that the insight provided by the proposition–that correlation of the outcomes pleads for competition through comparison in the optimal contract–is also a feature found under adverse selection, as first shown by Demski and Sappington (1984). The celebrated "Yardstick competition" regulatory tool (Shleifer, 1985) can be thought of as a version of Sappington and Demski (1983) with perfect correlation.

3.3 Tournaments and the value of comparison

The early literature on multiagent moral hazard has been concerned by the superiority of tournaments over independent incentive schemes under some circumstances. A tournament is a special form of RPE scheme in that it is based only on ordinal information. While RPE schemes are superior to independent contracts when results are positively correlated, the result does not in general carry through to tournaments because using tournaments as incentive device means throwing away a lot of information. As argued by Lazear and Rosen (1981), using only ordinal measure of performance may be justified by the greater cost of measuring results in absolute terms as compared to ordinal measures. When one looks closer into this argument, which has been extensively evoked, it is an argument relying on the ex-post comparisons of performance, rather than an argument based on ex-ante correlation of performances. We propose here a new simple way of capturing this aspect in the context of our model.

[10] Other more recent contributions include a large literature in corporate finance studying the incentives of CEOs and money managers (Admati and Pfleiderer, 1997; Aggarwal and Samwick, 1996, 1999; Abowd and Kaplan, 1999). See also Salas-Fumas (1992) and Luporini (2006) for applications in a firm setting.

In the present setting, a tournament amounts to the following grand contract: "the agent with the higher performance will receive a given high prize, while the other will receive a given low price". Two remarks are in order: First, this statement does not depend on how high the performance has to be in *absolute* terms. Second, we will assume as is customary that ties are broken according to a fair coin. Finally, given risk-neutrality and limited liability, it is straightforward to see that the loser's bonus will be optimally set to zero. Let W denote the winner's prize.

In order to capture the idea that *ordinal* information can be used on top of absolute evaluation in tournaments, we need to introduce the probability of being recognized as the best performer when it is indeed the case. Since agents are symmetric, when they choose the same level of effort they both have an ex-ante probability of winning the tournament of 1/2. In turn, let q be the probability of ending first in the tournament when choosing low effort, while the other agent chooses high effort. Then, since the principal can still rely on the cardinal information available (i.e. the signals R_i), this probability can not be higher than if the principal could not distinguish better performance in relative terms. In particular, this implies that necessarily $q \leq \frac{1}{2}$. Note that a completely random ranking, with $q = \frac{1}{2}$, can not occur as soon as $p_0 \neq p_1$, since the cardinal signals are then informative. Given the fair coin tie-breaking assumption, this is expressed as:

$$q \leq Prob(R_i > R_{-i}|0,1) + \frac{1}{2}Prob(R_i = R_{-i}|0,1)$$

$$\Leftrightarrow q \leq \frac{1}{2} - \frac{p_1 - p_0}{2}$$

Again, this is just a trivial observation, and can not be considered an assumption. Now, in order to compare piece-rate to tournaments, in the spirit of Lazear and Rosen (1981), we consider fully independent production. We know that in this case independent schemes are optimal if only the cardinal signals are used. However, as argued, tournaments may in some sense provide more information, since ordinal information is potentially easier to obtain. The incentive constraint under a tournament scheme with prizes W is simply:

$$\frac{1}{2}W - c \geq qW$$

from which we deduce that a pair of high effort is an equilibrium provided W is high enough, and that the optimal prizes is:

$$W^* = \frac{2c}{1-2q}$$

The nice feature of tournaments, as pointed out among other by Malcomson (1984), is that it entails a fixed amount of transfers to the agent–the prize W, here. Hence the minimal incentive cost under a tournament is exactly $\frac{2c}{1-2q}$. In turn, the (expected) incentive cost with an independent scheme, which again would constitute an optimal scheme in absence of additional ranking information, is $\frac{2p_1c}{p_1-p_0}$. It is easy to see that tournaments can thus do better than independent schemes if q is low enough. In particular, as q gets closer to 0, the incentive cost of a tournament converges to the first best level cost of giving incentives to both agents, $2c$. We summarize these observation in:

Proposition 3. *Under fully independent production, the optimal tournament strictly dominates independent contracts provided enough ordinal information is generated ($q < \frac{1}{2}\frac{p_0}{p_1}$). Moreover, if comparison is perfect ($q = 0$), the first best can be attained even in absence of any cardinal information on the performances ($p_1 = p_0$).*

Note that the condition for the optimality of tournaments is stricter than the condition obtained when remarking that cardinal information can still be used. Hence it is necessary that comparison provides strictly more information than cardinal information. It is quite easy to think of situations where this is the case. Suppose the agents are gathering strawberries in buckets, but the principal does not have scales. The evaluation of the weight of a bucket will entail significant measurement errors. In turn, determining which bucket is the heavier can be done with very small mistakes. In this case, the relative measure provides reliable ordinal information.

Following closely Lazear and Rosen (1981), a number of works have provided additional analysis of tournaments with multiple agents (Green and Stokey, 1983; Nalebuff and Stiglitz, 1983; Milgrom, 1988) and introduced correlation in the analysis (Nalebuff and Stiglitz, 1983; Mookherjee, 1984), confirming the insights discussed in the previous section. In our view, however, the value of comparison as modeled in those papers, which lean on performance correlation through correlated measurement errors, is to some extent misleading. Some work seems to be still required to capture more rigorously (and disentangle) correlation that is due to the productive environment (say, the price of oil as affecting the performance of oil firms' profits) and correlation that comes from measurement imperfection, as just described. In particular, the second type of errors is not relevant when all performance are measured in dollars or objective quantities, while it is highly relevant in situations of complex or subjective performances, even though there is no objective correlation of the first type in the production.

An important application of tournaments regards the hierarchical structure of firms and the incentives induced by promotions. For reasons outside of the scope of the analysis here, a principal may want to organize his firm in pyramidal structure (a hierarchy).[11] This form of orga-

[11] For instance Bolton and Dewatripont (1994)

nization induces agents to seek promotion opportunities, and the implied incentive structure is that of a multi-stage tournaments, as emphasized in Rosen (1986). This theme is also tackled by Malcomson (1984) or Prendergast (1999), who underline other desirable properties of tournaments, in particular as concerns the principal's commitment as discussed in a later section. It has also been argued that competition for promotion allows the principal to sort the workers who are the best qualified to occupy a job in a higher layer and have thus efficient dynamic allocation properties Lazear and Rosen (1981); Gibbons and Waldman (1999).

Finally, let us insist that the literature on tournaments deserves a full analysis on its own and has seen tremendous developments in the past decades. We refer the reader to the surveys by Corchn (2007) and Konrad (2007, 2009) for a comprehensive overview that is beyond the scope of this paper. This literature there takes as given that the incentives are provided through a contest structure, while we focus here on the more basic question of whether a contest is optimal in the first place.

show that a hierarchy is an efficient way to aggregate information in a firm when communication is costly.

3.4 Collective bonus and the cost of free-riding

Since Alchian and Demsetz (1972), it is widely acknowledged that collective production with undistinguishable contribution is the root to a free-riding phenomenon inside firms. The contribution of Holmström (1982) that is most put forward is his solution to this moral hazard in teams[12] problem with the intervention of a budget-breaking principal. This result should be interpreted slightly differently in the present context. The issue for a principal facing an aggregate team result is that there is a restriction imposed on the incentive scheme that stems from the limited information on individual performances: The principal observes only the aggregate result, hence can not distinguish between the outcomes (H, L) and (L, H). As a consequence, the incentive schemes necessarily features $w_{HL} = w_{LH}$. However, leaning on propositions 1 and 2, this is not an issue provided no weight is put on the outcomes (H, L) and (L, H) by the optimal schemes. This yields the following observation.

Proposition 4. *If the production exhibits complementarity and/or individual results are negatively correlated, non-observability of individ-*

[12]There are various ways to refer to this problem, "free-riding" being inspired by the old idea in public good financing, "moral-hazard-in-teams" having been popularized by Holmström (1982) and the "1/n problem" being used for instance in Prendergast (1999).

ual performances entails no additional cost for the principal compared to observable individual performances.

The proposition, while having an extreme flavor in our very stylized setting, underlines that free-riding is less of an issue when complementarities in production are present. In the extreme case of Leontieff production for instance (see Vislie, 1994), each agent is necessary in the production, and hence perceives the full benefit of his effort, which does not undermine its incentives compared to the social optimum. More generally, this problem may not be as severe as is often thought. Battaglini (2006) shows that when considering multidimensional inputs and multidimensional production the problem disappears provided the dimensionality of output is high enough compared to the average number of inputs controlled by the agents.[13] Another reason why the free-riding problem may not be as severe as emphasized by Alchian and Demsetz (1972) is that when the relationship is repeated, implicit contracts may provide the correct incentives, even with budget-balanced sharing rules. This has been demonstrated early by Macleod (1988) (see also Cremer, 1986, for a related insights in an overlapping generations framework).

The issue of optimal group incentives subject to budget-balance among agents is particularly important for the theory of partnerships, which, symmetrically to contest theory, is outside of the scope of this paper, since by assumption it studies the case in which no (third-party) principal can provide incentive.[14] Let us mention here a very original and interesting contribution by Gershkov, Li and Schweinzer (2009) that links the partnerships and contests literature. They show that a partnership with an information structure providing only ordinal information on performances can be used to design an efficient contest, thus overcoming the moral-hazard-in-teams problem.

3.5 Agents' Heterogeneity

It has been documented that dependent incentive schemes are affected by heterogeneity in terms of agents' ability. In the context of golf tournaments, Brown (2011) presents evidence that the participation of very high ability players has a negative effect on the performance of other players. Hansen (1997) studies service representatives of a financial institutions and find that the results of highly productive agents declines (while those of low productive agents increase) when individual

[13] See also Legros and Matsushima (1991); Legros and Matthews (1993); d'Aspremont and Gerard-Varet (1998) for related results on the information structure of generis moral-hazard-in-teams problem.

[14] Rayo (2007) aims at endogenizing the role of principal in partnerships, leaning on a model of relational contract (the relational contract approach is presented later).

rewards were substituted for by team rewards. In our framework, these results can be understood by looking at the agents' incentive compatibility constraints under dependent incentive schemes. A CPE scheme makes one agent's incentives positively depend on p_1, the probability of the other agent's high result (given that he undertakes the effort). A RPE scheme generates the opposite effect. [15] Therefore, low ability agents' motivation benefits from high ability agents under collective incentives while the contrary holds under competitive schemes. Therefore low ability workers should receive higher bonuses under competitive incentives while high ability workers should receive higher bonuses under collective incentives. The aforementioned evidence can be interpreted as heterogeneity in ability that is not accounted for by the incentive scheme and as a result undermines the motivation of either high or low ability workers.[16]

[15] A theoretical study of tournaments under heterogeneous ability can be found in O'Keeffe, Viscusi and Zeckhauser (1984)

[16] Relatedly, Hamilton, Nickerson and Owan (2003) find that heterogeneity in agents' abilities within a team increases the overall performance of this team. This finding can hardly be accounted for in our framework in terms of incentive effects. As the authors point it out, it may suggests some kind of technological spill over due to the most productive agents teaching the least able ones.

3.6 Other-regarding preferences

Until now, we have left aside an important dimension of the team problem that is currently under active scrutiny: the behavioral dimension of competition and cooperation.[17] In experimental as well as in theoretical contributions, a number of recent papers have tried to draw the consequences of and derive normative predictions for other-regarding preferences in incentives problem. A clear consequence of allowing for interdependent individual utility is that the incentive schemes has to be optimally interdependent, even though there are no *material* or informational links between the agents. As Milgrom and Roberts (1992) put it, "a given level of pay may be viewed as good or bad, acceptable or unacceptable, depending on the compensation of others in the reference group, and as such may result in different behavior. [...] This is a constraint on the use of any sort of incentive pay".[18] This has been recognized early by Frank (1984). Interestingly, this concern has also been raised on normative grounds by Meyer and Mookherjee (1987) long before the practical implications of inequity-aversion were included in contract design.

Itoh (2004) provides an extensive discussion of amendments of standard (expected) utility that may be of importance in teams

[17] See e.g. Fehr and Fischbacher (2002) for a motivation and an introduction.

[18] Milgrom and Roberts (1992, p. 419), cited in Englmaier and Wambach (2010).

problems. Obviously, concerns of fairness, inequity-aversion, altruism and the like[19] are highly relevant in contexts of interpersonal relationships at the workplace. In addition to those inequity-aversion dimensions, some authors have identified status seeking preferences, that is preferences such that the agents get a kick in utility when being "ahead" in terms of wages (see for instance Charness, Masclet and Villeval, 2010), while envy corresponds to disutility incurred when receiving a lower wage. Those preferences thus mirror the inequity-averse preferences mentioned above.

For the sake of expositional brevity, we focus here on inequity-averse preferences (the argument under status seeking preferences is then straightforwardly derived). Following Itoh (2004), the (ex-post) utility of an inequity-averse agent i is (note the slight abuse of notation on wages indices; the "+" notation indicates the positive part):

(6)
$$U_i = w_i - \alpha(w_{-i} - w_i)^+ - \lambda\alpha(w_i - w_{-i})^+$$

where $\alpha \geq 0$ parameterizes the intensity of other-regarding preferences and $|\lambda| \leq 1$ captures either inequity-aversion ($\lambda \geq 0$) when the agent is ahead ($w_i \geq w_{-i}$), though at a lower rate than when he is behind, or status seeking ($\lambda \leq 0$). Finally, we assume fully independent production to focus on the pure effect of other-regarding preferences. The next proposition follows from Itoh (2004), and the proof is not reproduced here:

Proposition 5. *With other-regarding preferences of the agents, the optimal scheme is as follows: if $\lambda > p_1(1-p_1)$, the optimal scheme exhibits CPE, and it is the same as in the absence of other regarding preferences. If $\lambda < \min\{p_1(1-p_1), \frac{1}{\alpha} - \frac{p_1(1-p_0)}{p_0(1-p_1)}\}$, the optimal scheme exhibits RPE and the optimal payment w_{SF} is decreasing in α and increasing in λ.*

Hence the optimal incentive schemes exploits the agents' social preferences in the expected way: when agents are sufficiently inequity-averse, team bonuses are optimal, while if their status seeking parameter is strong enough (λ sufficiently small, or α relatively small) then incentives are best provided through competitive schemes.

[19] Various theoretical papers deals with these issues, and the terminology is somewhat fluctuating. See also Grund and Sliwka (2005); Rey-Biel (2008); Chillemi (2008); Dur and Sol (2010); Englmaier and Wambach (2010); Bartling (2011) among many other closely related contributions. Dhillon and Herzog-Stein (2009) model status-seeking as rank-dependent utility. Bartling and von Siemens (2011) do not find significant experimental evidence of the effect of wage inequality, while Babcock et al. (2011) find important social effects in teams. Mohnen, Pokorny and Sliwka (2008) relate peer-pressure and inequity-aversion focusing on informational feedbacks.

3.7 Overconfidence

Another behavioral dimension under active scrutiny is overconfidence in relation to incentive problems. Following a large literature in psychology, agency theory has explored the effect of overconfidence biases and a number of experiments have been conducted. Similarly to the previously studied aspect of social preferences, however, it is probably too early to draw definitive conclusions on the magnitude of such biases and how they are dealt with in reality. That motivation and self-confidence interact is uncontroversial, but modeling attempts are still relatively new in economics (see Bénabou and Tirole, 2003; de la Rosa, 2011, for two interesting contributions based on different premises). Since overconfident agents tend to engage more in their activity, i.e. provide more effort, it may be desirable for the principal to boost their self-image. One aspect that is of particular interest in the design of multi-agent incentive schemes is how the principal can take advantage of mistaken beliefs of the agents and/or manipulate these beliefs. With mistaken beliefs, Santos-Pinto (2008) shows that in general the principal benefits from using interdependent schemes[20] even in absence of any other interdependence between agents. The intuition for the argument is quite clear: if an agent is overconfident in his ability compared to the other agent, an RPE scheme will require a lower payment than an independent scheme. Similarly, if agent i overestimate the ability of agent $-i$, he will be willing to accept a lower team bonus in a CPE scheme. Note that this line of reasoning need not even rely on *own* overconfidence, it is mostly a matter of how biased the belief in relative ability is.

As comes to whether the interdependence stemming from behavioral aspects is important relative to other aspects such as technology or information, this is a question that should be settled on a case-by-case basis, and it is probably more of an empirical exercise. As mentioned, those topics are currently under scrutiny by a growing community, and one can expect progresses in the coming years.

4 Organization and Peer Effects

In the previous sections we have studied optimal incentive schemes under the assumption that the agents behaved noncooperatively. A brand using franchising contracts with stores located in different cities may reasonably expect that the direct

[20] Other theoretical contributions include Gervais and Goldstein (2007) regarding teams and Santos-Pinto (2010) regarding tournaments. Field and laboratory experiments seem to confirm the importance of overconfidence in tournaments (Camerer and Lovallo, 1999; Park and Santos-Pinto, 2010) and teams (Vialle, Santos-Pinto and Rullière, 2011).

interaction between stores is limited. In such a case, the previous working assumption of Nash behavior is a reasonable one: the brand can design its incentive scheme considering that each store owner maximize his payoffs independently of others. However dependent schemes tie agents' interests to each other, and agents may benefit from coordinating their actions. The extent to which they can do so depends upon a number of factors, especially the organization of the firm. The non-cooperative behavior assumption becomes unreasonable when agents are in close interaction. Designing an incentive schemes for sellers working everyday in the same store must take into account the possibility of collusion/cooperation among agents. This section shows that in general this organizational dimension pleads for the use of collective incentives. The empirical literature has presented cases where firms preferred to set collective incentives even though the technology was independent (Herries, Rees and Zax, 2003) or cases where the introduction of collective incentives triggered an increase in overall performance (Chan, Jia and Lamar, 2012; Hamilton, Nickerson and Owan, 2003). The underlying mechanisms are broadly referred to as peer effects, which corresponds essentially to the idea that collective schemes align agents interests, thereby triggering beneficial cooperative behaviors among them. This section can be seen as distinguishing different kind of peer effects.

4.1 The agents' strategic perspective on CPE and RPE

Understanding the games among agents that RPE and CPE incentive schemes induce is a first step. We will consider only technologically independent productions for the sake of clarity. Accounting for correlation as done previously is quite straightforward.[21] The game-theoretic and efficiency properties of CPE and RPE from the point of view of the agents are very different. Before introducing coalitional/collusive behaviors of agents, we give a strategic analysis of CPE and RPE.

4.1.1 CPE and multiple equilibria

First, the game between agents induced by a CPE scheme exhibits multiple equilibria. This may be problematic in some circumstances. Consider indeed the optimal CPE schemes as defined previously. By definition, is it such that an agent's incentive constraint is binding *when the other agent exerts*

[21] An additive correlation parameter γ shifts all the payoffs by an amount $\gamma(w_{HH} + w_{LL} - w_{HL} - w_{LH})$, which is neutral in terms of incentives and strategic interaction between the agents. Hence the analysis undertaken below carries through directly to this case. The case of technological interaction is in turn slightly more involved, but it yields the same insights.

Table 1: CPE with independent production

	$e_2 = 1$	$e_2 = 0$
$e_1 = 1$	r, r	$r - c, r$
$e_1 = 0$	$r, r - c$	$\frac{p_0}{p_1}r, \frac{p_0}{p_1}r$

effort. This means however that the equilibrium $(1, 1)$ is not robust to small perturbation. If for some reason agent $-i$ does not work with a small probability ε (a small mistake, say, a tremble), then the incentive constraint of agent i is not satisfied, and $e_i = 0$ becomes the unique best-reply. The other equilibrium of the game induced by CPE is $(0, 0)$. This equilibrium is robust to tremble. To further investigate those aspects, we use the totally independent case as mentioned (the insights of course carry through to the cases where CPE is the only optimal scheme). In this case, the optimal CPE bonus is $w_{HH} = \frac{c}{p_1(p_1-p_0)}$ and the normal form of the game between agents has the structure given in table 1 (payoffs are in expectation), where $r = \frac{p_0 c}{p_1-p_0}$, and is equal to the rent obtained in the optimal independent scheme.[22]

The game is such that there are two pure-strategy equilibria, one which is Pareto-dominant, $(1, 1)$ but not robust to tremble, and a Pareto-dominated one which is robust to tremble. It is tempting to focus on the Pareto-dominating equilibrium, all the more so that it is also the principal's preferred outcome, and that is what we do in the following, but one should still keep in mind the issue of multiple equilibria.[23]

4.1.2 RPE as a prisoner's dilemma

Regarding RPE, insights are quite different. The strategic structure imposed by RPE resembles a (non strict) prisoner's dilemma. Let us illustrate the strategic issue from the agent's point of view, again using the case of totally independent production as a benchmark. There the optimal RPE bonus is $w_{HL} = \frac{c}{(1-p_1)(p_1-p_0)}$, which induces the game in table 2. The most important feature of this game is that is consists of a prisoner's dilemma, with $e_i = 1$ being a (weakly) dominant strategy.[24] Hence outcome reached when the effort pair is $(0, 0)$ Pareto dominates the $(1, 1)$ equilib-

Table 2: RPE with independent production

	$e_2 = 1$	$e_2 = 0$
$e_1 = 1$	r, r	$r + \frac{p_1}{1-p_1}c, r$
$e_1 = 0$	$r, r + \frac{p_1}{1-p_1}c$	$\frac{1-p_0}{1-p_1}r, \frac{1-p_0}{1-p_1}r$

[22] It is readily checked that $r - c < \frac{p_0}{p_1}r$, as argued above.

[23] Macleod (1987) argues that collective incentives requires coordination of agents, which is likely to necessitate learning about each other's behavior. As a result, collective incentive schemes are less likely to be present in sectors in which workers' mobility is high.

[24] It is of course the case that $r + \frac{p_1}{1-p_1}c > \frac{1-p_0}{1-p_1}r$. Since an agent is indifferent between exerting effort or not when the other chooses $e_{-i} = 1$, he must be better off choosing $e_i = 1$ when $e_{-i} = 0$.

rium outcome, but it can not be attained in a Nash equilibrium. As the next section demonstrates, this makes RPE schemes not robust to collusion. Finally, since the game is not a strict prisoner's dilemma, $(1, 0)$ and $(0, 1)$ are also Nash equilibria, and they both Pareto-dominate the situation $(1, 1)$. However, as noted by Ishiguro (2002), it is easy to knock them out by adding an arbitrarily small amount to the wage w_{HL}. This at the same time makes the game a strict prisoner's dilemma.

4.2 Collusion

The extreme form of coordination for the agents consists in signing (side-)contracts to committing themselves to reaching a given outcome. We assume in this subsection that agents collude by side-contracting on monetary transfers conditional on the pair of outputs. By doing so, they can actually change the game induced by the incentive scheme, and possibly its equilibria. This clearly adds new constraints to the principal's problem since the incentive scheme must be designed so that agents cannot improve their expected payoff by changing the induced game. A result by Holmström and Milgrom (1990) and Hideshi (1993) follows:

Proposition 6. *When efforts are not observable, the principal cannot benefit from agents side-contracting on the pair of results.*

A way of understanding this result is to remark that whatever the conditional transfers chosen by the agents, the resulting game between agents could have been induced by the initial incentive scheme.

Nevertheless, due to the differences in the game between agents they induce, (pure) RPE and (pure) CPE incentive schemes are differently affected by the possibility that agents collude.[25]

Proposition 7. *CPE incentive schemes are robust to collusion, so that the possibility of collusion does not increase the cost of CPE schemes.*

To see this, note that the equilibrium pair of efforts $(1, 1)$ of the game between agents induced by a CPE scheme is Pareto optimal from the agents' point of view. Therefore, agents have no incentive in side-contracting since reaching another pair of effort would induce a loss in the aggregate expected utility.

On the contrary, RPE schemes are strongly affected by collusion among agents.

Proposition 8. *A RPE scheme with binding incentive compatibility constraints is not robust to collusion. Collusion therefore increases the cost of RPE schemes.*

As previously pointed out, an optimal RPE scheme (without collusion) places

[25] We restrict the analysis to pure schemes. Clearly this is not without loss of generality, as it might well be the case that the optimal incentive schemes when agents can collude be a mixed RPE or CPE scheme. To our knowledge, a systematic analysis of the optimal incentive under collusion is still to be done.

agents in a prisoner's dilemma, where the pair of efforts $(0,0)$ Pareto dominates $(1,1)$. Now, consider the following side-contract: agents commit to exchange bonuses following any pair of results. Under a pure RPE scheme, this means that an agent can only earn a bonus when he gets a low result. This makes $(0,0)$ the only Nash equilibrium of the modified game, and this side-contract makes both agents better off.[26] Therefore, implementing the pair of efforts $(1,1)$ with a RPE scheme robust to collusion entails a greater cost than in the absence of side-contracting.

4.3 Mutual monitoring

An important feature of organizations is that agents often have superior information about their peers' efforts as compared to the principal (Edwards and Ewen, 1996). This subsection studies how the principal can use this additional information to enhance incentives. Clearly, the principal would like to extract this information if possible, that is, to induce whistle-blowing. We first show that the moral hazard problem can be totally overcome by designing an appropriate communication mechanism, but that such a mechanism is not robust to collusion. We then return to the issue of whether incentives should be competitive or collective under the assumption of mutual monitoring, showing that CPE schemes allow to use the private information detained by agents while being collusion proof.[27]

4.3.1 Whistle-blowing and first-best implementation

When agent's observe each other's action, the principal can design a stage game in which agent's are induced to report the other's effort truthfully, and implement the first-best.[28] An agent receives a transfer c if and only if he has not been turned in. In order to obtain an informative signal, it is possible to add a communication round after the agents have chosen their effort, but before outcomes are realized. It is sufficient to offer a contract as follows: "you will receive a bonus for reporting a low effort of the other. But if it happens that the other obtains a success, you will be punished by a higher amount." When properly calibrated, such a whistle-blowing mechanism incites agents to report deviation by their teammate, but does not induce them to always do so thanks to the conditional punishment.

However, such a mechanism is subject to two problems: first, it may not respect limited liability in all cases, and second, it has a Pareto-dominating equilibrium (from

[26]Note that agents could also deviate toward the pair of efforts $(1,0)$ ($(0,1)$) by agreeing on agent 1 (2) giving a share of his bonus to agent 2 (1).

[27]An important application of those and related ideas is group lending in developing economies, see e.g. Ghatak and Guinnane (1999) for an overview.

[28]This was first proved by Ma (1988), using a clever mechanism of "integer games". However the practical aspects of such modified mechanisms have been questioned in the subsequent literature.

the point of view of the agents) that is not the desired one. Regarding the first point, one can correct this by adding an arbitrarily small amount to the agent's payoff. In turn, the second point is a bit more tricky to overcome. We propose a slight variation of the mechanism that allows unique implementation without violating the limited liability constraint (for the very same reason as the one just mentioned in the first point). The details of the implementation are relegated to the appendix. The mechanism is a modification of the one proposed in Laffont and Rey (2003), which is plagued by a multiple equilibria problem.[29] Under their mechanism, there exists a "bad" equilibrium that Pareto-dominates the one desirable for the principal, in which agents work and report truthfully. In the best equilibrium for the agents, they never work and never turn in their teammate. The scheme proposed in the appendix is not subject to this problem.

Proposition 9. *When the agents mutually observe their efforts, the principal can approximate the first-best, implemented as a Nash equilibrium which is Pareto-dominating from the agents' point of view.*

As pointed out by Brusco (1997), such a mechanism is not robust to collusion. For instance, agents could commit to exchange bonuses and therefore would have clear incentives in not working without reporting it to the principal. Not satisfying collusion-proofness is an important shortcoming in this context since agents being able to monitor each other should also be able to behave cooperatively.

Peer evaluation (known by practitioners as 360 degree evaluation) has become increasingly popular in firms but not necessarily for incentive purposes (they are rather used for personal development of employees). As argued by Towry (2003), the reluctance of firms to base incentives to peer evaluations (Coates, 1998) can be seen as a result of their sensitivity to collusion.

4.3.2 Delegated Cooperation

As a result of mutual monitoring, agents can side-contract both on monetary transfers and on the chosen efforts. We ask how this affects the optimal incentive scheme and the principal's expected gain. These questions were first answered by Varian (1990) and Ramakrishnan and Thakor (1991), who showed in a setting with risk averse agents and no limited liability that the optimal contract is a CPE scheme and that the principal actually benefits from the supplementary information held by the agents. Unlike incentives based on revelation mechanisms, coalitional behavior from the agents is profitable for the principal. We derive similar results with risk neutral agents and limited liability.

We assume that tasks are independent

[29] See also Brusco (1998, 2002) and Ishiguro and Itoh (2001).

(both informationally and technologically), that is $p_{e_1,e_2} = p_{e_1}p_{e_2}$. Since agents side-contract on the pair of efforts, they behave as a coalition, or using Wilson (1968)'s terminology, as a syndicate: they jointly choose the pair of effort that maximizes the sum of their expected gains. Given the symmetry of the problem, we can assume that agents share the surplus equally without loss of generality. Considering that he faces a coalition, the principal can provide collective bonuses conditional on the aggregate output. [30] Let us denote by W the collective wage associated to a pair of successes and w the wage when only one succeeds (the optimal bonus obtained when both agents fail must obviously be 0). The expected remuneration of the coalition associated with the pair of effort (e_1, e_2) is:

$$\mathbb{E}_{\boldsymbol{R}}^{C}\left[W_{\boldsymbol{R}}|e_1,e_2\right] = p_{e_1}p_{e_2}W + p_{e_1}(1-p_{e_2})w + p_{e_2}(1-p_{e_1})w.$$

The optimal incentive scheme must prevent the coalition from deviating from $(e_1, e_2) = (1,1)$, that is it must satisfy

$$\text{(7)} \qquad \mathbb{E}_{\boldsymbol{R}}^{C}\left[W_{\boldsymbol{R}}|1,1\right] - \mathbb{E}_{\boldsymbol{R}}^{C}\left[W_{\boldsymbol{R}}|0,1\right] \geq c$$

and

$$\text{(8)} \qquad \mathbb{E}_{\boldsymbol{R}}^{C}\left[W_{\boldsymbol{R}}|1,1\right] - \mathbb{E}_{\boldsymbol{R}}^{C}\left[W_{\boldsymbol{R}}|0,0\right] \geq 2c,$$

as well as the limited liability constraints

$$\text{(9)} \qquad W, w \geq 0.$$

The principal then solves the following problem:

$$\min_{W_{\boldsymbol{R}}} \mathbb{E}_{\boldsymbol{R}}^{C}\left[W_{\boldsymbol{R}}|1,1\right]$$
$$\text{subject to (7), (8), (9).}$$

Comparing the incentive efficiencies of W and w with respect to constraints (7) and (8), it is found that W always dominates w. Therefore, the optimal incentive scheme is a CPE scheme. It can be checked that constraint (8) is binding so the optimal incentive scheme for the coalition is

$$W = \frac{2c}{p_1^2 - p_0^2} \quad \text{and} \quad w = 0.$$

The expected remuneration of one agent under this scheme is

$$\frac{p_1^2 c}{p_1^2 - p_0^2},$$

which is lower than the expected remuneration under the independent contract, i.e. $\frac{p_1 c}{p_1 - p_0}$. Therefore the principal is better off when agents act as a coalition.

[30] Note that neither agent will have an incentive to deviate from the effort chosen by the coalition. Indeed, each agent gets a fixed share of the coalition's bonus across results. An agent deviating would decrease the coalition's expected bonus and in turn decrease his own expected bonus.

Proposition 10. *Suppose that tasks are independent. If agents observe each others' effort and behave as a coalition, the optimal incentive scheme is a CPE scheme, and the principal is better off than in the case where agents behave non-cooperatively.*

A way of understanding the optimality of CPE schemes is to draw a parallel with the optimal incentive scheme of an agent that works on several tasks. As shown by Laux (2001), if the principal wants his agent to work on all tasks, then it is efficient to give him a positive bonus only if he succeeds in all tasks. In other words, there are economies of scale on the limited liability rents. The fact that the principal is better off when facing a coalition than when facing two isolated agents can be understood as follows: when tasks are independent and agents make decisions separately the optimal incentive scheme can be cooperative, competitive or independent. A cooperative (competitive) scheme makes agents efforts complementary (substitutable). These positive (negative) externalities associated to efforts matter if agents can make decisions cooperatively because they will be internalized. This makes the incentives provided by a cooperative (competitive) scheme more (less) effective when agents behave as a coalition. [31]

As noted earlier, these results were expressed in the literature in a risk aversion setting (Holmström and Milgrom, 1990; Varian, 1990; Itoh, 1992; Macho-Stadler and Perez-Castrillo, 1993). The logic of our results also applies there, the improvement when agents choose efforts cooperatively simply takes the form of decreased risk premium instead of decreased liability rent. In addition, when agents are risk-averse, coalitional behavior increases risk-tolerance thereby allowing better risk sharing among the principal and the two agents (Borch, 1962; Wilson, 1968).

4.3.3 Relational contracts between agents

One strong assumption in the previous analysis was that agents were able to sign side-contracts in order to enforce their coalitional behavior. Such contracts are in general not feasible,[32] even though agents may be able to mutually observe their efforts. In turn the absence of explicit contracts can however be substituted for by relational contracts in long-run relationships. Hence, inducing the agents' to use relational contracts may be desirable for the principal, in the very same spirit as delegated cooperation.

Che and Yoo (2001) study a dynamic setting in which enforcement of coalitional

[31] The extent to which this result holds when tasks are not independent is discussed at the end of this section.

[32] This is most often the case in organizations. See for instance Brusco (1997, pp. 400-401) for a discussion on this point and corresponding modeling assumptions.

behavior stems from cooperation in a repeated framework, in the spirit of the folk-theorem.[33] In their model, the principal chooses an incentive scheme once and for all at the beginning of the game (one may think of this stage as the institutional design stage), and agents then play an infinitely repeated version of the by now familiar static game. They demonstrate that CPE does a better job at implementing effort by both agents in the long run precisely by making relational contracts more effective than under RPE. The point they make is that even under circumstances in which RPE would be optimal in a static framework, because there is positive correlation and collusion is infeasible, CPE still becomes optimal for the principal in a dynamic setting. The point is that a form of delegated cooperation is feasible when agents are sufficiently patient and have mutual punishments available. CPE typically offers the best threats between agents, which makes their coordination on high efforts easier. We replicate their argument in the case of independent production but positive correlation.

Recall that in the static problem, obtaining $(1, 1)$ as a Nash-equilibrium writes:

$$\mathbb{E}_{\boldsymbol{R}}\left[w_{\boldsymbol{R}}|1,1\right] - c \geq \mathbb{E}_{\boldsymbol{R}}\left[w_{\boldsymbol{R}}|0,1\right].$$

In turn, obtaining the infinite repetition of $(1, 1)$ as a subgame perfect Nash equilibrium entails that an agent should not want to shirk at a given period, in particular when he would continue to shirk afterwards. Hence it is necessary that:

$$\begin{aligned}\mathbb{E}_{\boldsymbol{R}}\left[w_{\boldsymbol{R}}|1,1\right] - c \geq (1-\delta)\mathbb{E}_{\boldsymbol{R}}\left[w_{\boldsymbol{R}}|0,1\right] \\ + \delta \min_{e_{-i}} \mathbb{E}_{\boldsymbol{R}}\left[w_{\boldsymbol{R}}|0,e_{-i}\right],\end{aligned} \tag{10}$$

where the payoffs are average discounted payoff–i.e. normalized so that they are comparable to the static ones. It is thus apparent from the second term of the right hand side that repetition may relax the incentive constraint compared to the one-shot case. Now the question is: what is the best way of exploiting this additional freedom? If the scheme is a RPE scheme, then an agent is more punished when the other agent exerts effort than when he does not. Hence with an RPE scheme, $\min_{e_{-i}} \mathbb{E}_{\boldsymbol{R}}\left[w_{\boldsymbol{R}}|0,e_{-i}\right] = \mathbb{E}_{\boldsymbol{R}}\left[w_{\boldsymbol{R}}|0,1\right]$ and the constraint is at best the same as the static one. Therefore RPE in a dynamic setting can not do better than in the static framework. In addition, under an RPE scheme, the pair of efforts $(1, 1)$ is Pareto-dominated from the agents point of view by asymmetric effort pairs. Hence in this repeated setting where a folk theorem applies, they can attain better payoffs, for instance by alternating effort pairs $(1, 0)$ and $(0, 1)$. This could be implemented with classical punishment: in case an agent ex-

[33] See Levin (2002) for a related contribution, which is discussed in the last section. The idea that teamwork can be enforced in a repeated setting can also be found in Macleod (1988).

erts effort while equilibrium play requires him not to exert effort, the other can punish him in every future period, and they end up playing $(1,1)$ forever, which indeed constitutes a subgame-perfect Nash equilibrium as $(1,1)$ is a Nash equilibrium in the one-shot game.

In turn, under CPE, an agent is all the more punished that his teammate does not work (irrespective of his own effort). Hence the necessary constraint (10) becomes:

$$\mathbb{E}_{\boldsymbol{R}}\left[w_{\boldsymbol{R}}|1,1\right] - c \geq (1-\delta)\mathbb{E}_{\boldsymbol{R}}\left[w_{\boldsymbol{R}}|0,1\right] + \delta\mathbb{E}_{\boldsymbol{R}}\left[w_{\boldsymbol{R}}|0,0\right],$$

which is easier to satisfy than the static one. Moreover, since CPE makes effort complementary in the eyes of the agent, an agent is better off choosing $e_i = 0$ when $e_{-i} = 0$. Hence $(0,0)$ forever is indeed a subgame-perfect punishment. The optimal CPE scheme in the repeated setting is then simply obtained when the constraint binds, which yields the optimal long term CPE bonus:

$$w_{HH}^{\infty} = \frac{c}{p_1(p_1 - p_0) + \delta p_0(p_1 - p_0)}.$$

This is always lower than the static CPE bonus, which obtains for $\delta = 0$. Hence while RPE in a repeated setting can not improve on the principal's cost compared to the static benchmark, CPE lowers the cost of incentives. We conclude with a synthetic proposition.

Proposition 11. *In a repeated interaction setting where agents mutually observe efforts, CPE is relatively more efficient than RPE by inducing better peer discipline.*

Economists have recently provided empirical evidence of the relevance of collusive or coalitional behavior of agents on the efficiency of incentive schemes. Bandiera, Barankay and Rasul (2005) show from personnel data of a fruit farm that the change from competitive incentives to independent incentives increased the productivity of the average worker of 50%. They show that the weak effectiveness of the competitive incentive scheme was due to agents who were able to monitor each other's efforts, arguing for detrimental coalitional behavior. Symmetrically, Knez and Simester (2001) argue that the increase in employee performance at Continental Airlines following the introduction of collective incentives is imputable to the mutual monitoring among employees within work groups.

4.4 Help and Sabotage

If agents often interact, they may be able to undertake actions that affect the probability of success of their co-workers. Those actions can be beneficial (*help*) or detrimental (*sabotage*). CPE schemes turn out to be more effective in both cases as noted by Itoh (1991), Milgrom (1988), Lazear (1989), Kandel and Lazear

(1992), Macho-Stadler and Perez-Castrillo (1993) and Drago and Garvey (1998). This simply comes from the fact that collective schemes gives incentives to undertake actions that are beneficial from the collective point of view, that is agents will help co-workers when it is optimal and they will not waste resources trying to undermine others' work.[34] Competitive schemes would provide the opposite incentives which would clearly be inefficient from the principal's point of view. Social-psychologists have been interested for a long time in the relation between what they call "task interdependence" (which corresponds in this literature to the fact that subjects can and should help each other in their tasks) and the relative efficiency of collective and competitive incentives. Numerous experimental studies allowed them to early reach the same conclusions as economists (Miller and Hamblin, 1963). In the field of experimental economics, recent studies such as Harbring and Irlenbusch (2011) and Dye (1984) provide evidence of sabotage behavior in tournaments.

4.5 Organization as Choice Variable

We can build on the preceding results to draw insights on the way a principal should design his organization. Following the analysis of Ramakrishnan and Thakor (1991), we assume that the principal chooses whether or not agents can cooperate as well as the incentive scheme. We call this joint decision a system. Preceding results argue for two polar systems. If the principal is to set a RPE scheme, then he should avoid any contact between his agents so as to avoid collusion. We say in this case that the principal chooses a *separated system*. On the contrary, if the principal is to set a CPE scheme, then he should make his agents work together in order to induce beneficial coalitional behavior. We say in this case that the principal sets an *integrated system*.

Proposition 12. *If the principal can choose both the organizational design and the incentive scheme, then the only systems potentially optimal are the integrated and separated systems.*

As shown by Ramakrishnan and Thakor (1991), when the organization of work is endogenous, the relation between the interdependence of tasks (either technological or informational) and the optimal incentive scheme is "biased" towards CPE schemes. We have seen that interdependences could imply that efforts are either substitutable or complementary which in turn calls for competitive or cooperative incentives respectively. We show that an integrated system is optimal for low levels of effort substitutability, which implies

[34] The literature on tournaments and contests has been concerned with sabotage since a few years (Chen, 2003; Mnster, 2007).

that a CPE scheme is chosen even though efforts are substitutable. This is due to the fact that coalitional behavior from the agents induces gains for the principal when the incentive scheme is cooperative independently of the tasks interdependences. If efforts are substitutable, then the principal faces the following trade-off: choosing an integrated system in order to benefit from coalitional behavior or choosing a separated system in order to exploit this substitutability. In order to make this point in our model we assume that results are correlated and we show that there is a positive cut-off value of correlation under which the principal finds it optimal to use an integrated organization.[35] We set the correlation parameter γ as in the preceding sections. To find the cut-off value of γ, we compute the expected remuneration of agents under the two alternative systems as a function of the correlation parameter γ. The expected remuneration of one agent in the separated system is

$$(p_1(1-p_1)-\gamma)\frac{c}{(1-p_1)(p_1-p_0)},$$

which is decreasing in γ, while the expected remuneration of an agent in the integrated system is

$$(p_1^2+\gamma)\frac{c}{(p_1-p_0)(p_1+p_0)},$$

which is increasing in γ.[36] A RPE scheme is then optimal when $\gamma \geq p_0 p_1 \frac{(1-p_1)}{1+p_0)}$.

Proposition 13 (Optimal Organizational Design)**.** *There is a strictly positive cut-off value of correlation above which the principal finds it optimal to set a separated system and under which he prefers a integrated system. Therefore, when the principal jointly chooses the organization of work and the incentive scheme, collective incentives can be optimal even though efforts are substitutable.*

To conclude this section, let us mention that a number of other organizational issues studied in the multi-agent moral hazard framework are outside of the scope of this survey. For instance, Macho-Stadler and Perez-Castrillo (1998) and Baliga and Sjöström (1998) study the incentive issues that arise when the principal can structure his organization vertically, i.e. contract with one agent which is himself responsible for contracting with the other agent. Maskin, Qian and Xu (2000) relate the relative value of two kinds of hierarchical organizations to how well they take advantage of the correlation between agents' results using RPE. Gromb and Martimort (2007) study the design of incentive contracts for experts under both adverse selection and moral hazard, and they show that experts should

[35] The same exercise could have been performed with a technological based substitutability.

[36] It can be shown that the expected gain of an agent is given by this equation as long as $\gamma \leq p_0 p_1$, which is greater than the cut-off value of the correlation.

be paid according to a mix of IPE and (some form of) CPE.

5 Commitment and Relational Contracts

We have assumed until now that the provision of incentives was only constrained by the agents' limited liability. This section introduces additional contracting limitations and studies their implications on the optimal incentives.

5.1 Principal's moral hazard

A first contracting restriction occurs when the principal is able to affect agents' productivity through an unobservable effort. An example of such a case is given by Gould, Pashigian and Prendergast (2005) who study contracts proposed by the developer of a mall (the principal) to the owners of shops (agents) selling products in the mall. They argue that contracts must provide incentives to both the owners and the developer as the developer can undertake unobservable efforts affecting the shops' sales (e.g. actions involving cleanliness, renovation, parking). Such a situation is referred to as two-sided moral hazard and has received attention in the multi-agent moral hazard literature since Carmichael (1983), followed by Al-Najjar (1997) and Gupta and Romano (1998). These papers all show that moral hazard on the principal's side calls for more competition on the agent's side. We adapt the argument of Gupta and Romano (1998) to our model.[37]

Consider the following setting in which the principal can exert an additional effort. The two projects of the agents are fully independent, so that only w_{HH} or w_{HL} will be optimally positive, but the results of their project depend on an effort by the principal in the following way: if the principal chooses zero effort (at zero cost), the agents' probabilities of success are q_e, while they are $p_e > q_e$ for any e when the principal undertakes the effort, at a cost c_P. Hence success is obtained more often when the principal chooses to exert effort. We look for the condition on the principal's cost under which the principal is indeed incited to exert effort. Let us set the value of a high result to B and normalize the value of a low result to 0. With independent schemes, the principal's incentive constraint is:

$$2(p_1 B - p_1 w_H) - c_P \geq 2(q_1 B - 2q_1 w_H),$$

which can be rewritten as:

$$c_P \leq 2(p_1 - q_1)(H - L - w_H).$$

The case where the principal contracts independently with either agents corresponds to the classic two-sided moral hazard prob-

[37] See also Itoh (1994) and Tsoulouhas (1999) for related contributions.

lem. Providing incentives to the principal and to either of the agents are conflicting goals, since all of them must be rewarded following a good outcome. This issue can be either mitigated or amplified using competitive and collective schemes respectively. In a competitive scheme, agents are only rewarded when one of them obtains a high result. This allows the principal to partially decouple his own incentives from the agents' since he is only "rewarded" (in the sense of not paying bonuses) following a *pair* of high results. On the contrary, a collective scheme concentrates the incentive antagonism on the case of a double success.

This can be checked by expressing the principal's incentive constraints as in the independent case. Using the fact that $w_{HH} = w_H/p_1$ and $w_{HL} = w_H/(1-p_1)$, the principal's incentive constraints under CPE and RPE schemes are respectively:

$$c_P \leq 2(p_1 - q_1)(B - \left(1 + \frac{q_1}{p_1}\right) w_H)$$

and

$$c_P \leq 2(p_1 - q_1)(B - \left(1 - \frac{q_1}{1-p_1}\right) w_H).$$

Therefore, the incentive constraint of the principal is satisfied for a higher cost c_P when RPE is used. The next proposition follows:

Proposition 14. *Suppose that the projects are independent and that the principal can take a non-contractible action that increases the probabilities of success. Then a RPE scheme provides more incentives to the principal than an IPE scheme, which itself provides more incentives than a CPE scheme.*

5.2 Principal's Commitment

A major limit on incentive provision is the risk of renegotiation of the announced remuneration. When results are not verifiable, the principal is not necessarily able to commit to pay bonuses as specified in the contract. As agents fear the possibility of hold-up from the principal, incentives become ineffective. Typically, the remuneration in law firms involves discretionary bonuses that are partly based on subjective evaluation of performance, which makes the commitment problem salient (Levin, 2003). We present two prominent ways of dealing with this issue: using tournaments and relying on relational contracts.

5.2.1 Tournaments as Credible Incentives

Tournaments perform well when relative measurement of performance is more accurate than absolute measurement. Malcomson (1984, 1986) shows that tournaments can also constitute a good commitment means for the principal to pay bonuses as specified in the contract. If the outputs of the agents are observable but not verifiable in courts, the principal always has an incentive to claim that the agents failed in order not to pay bonuses.[38] A tournament overcomes this problem because rewards are only based on the ranking of agents' results. The aggregate bonus is then independent of the principal's evaluation of performances so the principal cannot increase his payoffs by under-evaluating agents' results. Incentives can be provided as long as the principal can commit to pay a fixed amount of money.

5.2.2 Multilateral Relational Contract and Competitive Incentives

Another way of providing incentives when results are not verifiable is to rely on reputation in long run relationships. The literature on relational contracts has been growing quite rapidly over the past ten years.[39] When the contractual relation is repeated over time, hold up from the principal can be prevented through the threat of the agents ending the relationship. The principal's commitment to stick to the terms of the contract will be credible if the continuation value of the relationship is greater than the instantaneous profit he would obtain by not paying the appropriate bonus. This additional requirement puts an upper bound on credible bonuses which is usually referred to as a self-enforcement constraint.[40] As pointed out by Levin (2002), the threat is even stronger in a multi-agent setting if *all* agents stop working following a deviation from the principal with only *one* of them. In this case the incentive scheme must satisfy an aggregate self-enforcement constraint instead of one self-enforcement constraint per agent, making the principal's commitment less problematic. Levin (2002) shows that facing an aggregated SE constraint calls for competition as an optimal incentive scheme. Intuitively, it is as if the principal faces a budget constraint on the (ex-post) sum of rewards he can promise following each pair of results. RPE schemes obtain because the optimal distribution of this amount following each pair of results requires a comparison of the incentive efficiencies of bonuses between agents. The reward of the agent with a relatively low result must be used to subsidize the bonus of the relatively high result. In Levin (2002)'s framework, this calls for tournament-like incentive scheme where agents only receive a (fixed) bonus if their output outperforms that of the other agent.[41] Kvaløy and Olsen (2006) show in a setting similar to ours that multilateral relational contracts tend to call

[38] Prendergast (1993) makes a related argument in considering promotions as a means to credibly reward specific human capital acquisition by agents.

[39] See in particular Levin (2003); MacLeod (2003) for seminal contributions. MacLeod (2007) and Malcomson (2010) survey this literature.

[40] Note that this constraint could be interpreted as a form of limited liability constraint of the principal, since it bounds the ex post amounts of money the principal can transfer to the agent. However this bound is endogenous, since it depends on the contract itself.

[41] When both agents perform poorly, none of them get a bonus.

for competitive incentives, but their results are less clear-cut than the results of Levin (2002) as we shall now see.[42]

Consider the repeated version of our static model where tasks are totally independent. The principal wants to make both agents work in each period at a minimal cost. The incentive scheme must solve the familiar static incentive problem.[43] As stated above, the incentive scheme must also satisfy (aggregate) self-enforcement constraints so that the principal can credibly commit to pay bonuses as specified in the contract. These constraints require the sum of individual bonuses following every pair of outputs to be lower than the continuation value of the multilateral relationship to the principal. We assume as in the previous section that the value of high and low results are B and 0, respectively. The expected instantaneous profit per agent working then is $p_1 B - \mathbb{E}_{\boldsymbol{R}}\left[w_{\boldsymbol{R}}|1,1\right]$ where $\mathbb{E}_{\boldsymbol{R}}\left[w_{\boldsymbol{R}}|1,1\right] = p_1^2 w_{HH} - p_1(1-p_1)w_{HL}$ (recall that an agent is never paid after a low result). If the principal deviates with any one agent, both agents break the contract and the principal gets a profit normalized to 0 in all subsequent periods. Let δ be the common discount factor. The net continuation value of the two relationships is $2\,\delta/(1-\delta)\,(p1B - p_1^2 w_{HH} - p_1(1-p_1)w_{HL})$. Self-enforcement of an incentive scheme requires this value to be higher than w_{HL}, the aggregate payment of the principal following results HL and LH. Similarly, the continuation value must be higher than $2w_{HH}$, the aggregate payment following results HH. The former constraint is noted SE_{HL} in figure 2, while the latter is noted SE_{HH}.

Restricting attention to optimal contracts, i.e. contracts that make the incentive constraint binding, simplifies the analysis. Provided that tasks are totally independent, the net continuation value can be rewritten as $\delta/(1-\delta)\,[p_1 B - p_1 c/(p_1 - p_0)]$ which is independent of w_{HH} and w_{HL}. As a result, the self-enforcement constraints become simple upper bounds on w_{HH} and w_{HL}:

$$w_{HH} \leq \frac{\delta}{2(1-\delta)}(p_1 B - \frac{p_1 c}{p_1 - p_0}),$$

$$w_{HL} \leq \frac{\delta}{1-\delta}(p_1 B - \frac{p_1 c}{p_1 - p_0}).$$

The bound on the collective bonus is thus twice lower than the bound on the competitive bonus. This is a simple consequence of competitive bonuses being spread out across results HL and LH and collective bonuses being both distributed following

[42] Kvaløy and Olsen (2006) actually consider both relational contracts between the principal and the agents and among agents. Their results then involve the mechanisms from Che and Yoo (2001) that we reported in the third section. In this section, we only focus on relational contracts between the principal and the agents, assuming that agents behave noncooperatively.

[43] Under this assumption, we preclude the possibility of disciplining the agents by a threat of firing, i.e. of losing a stream of limited liability rents. This could be done for instance by using review contracts as in Fuchs (2007).

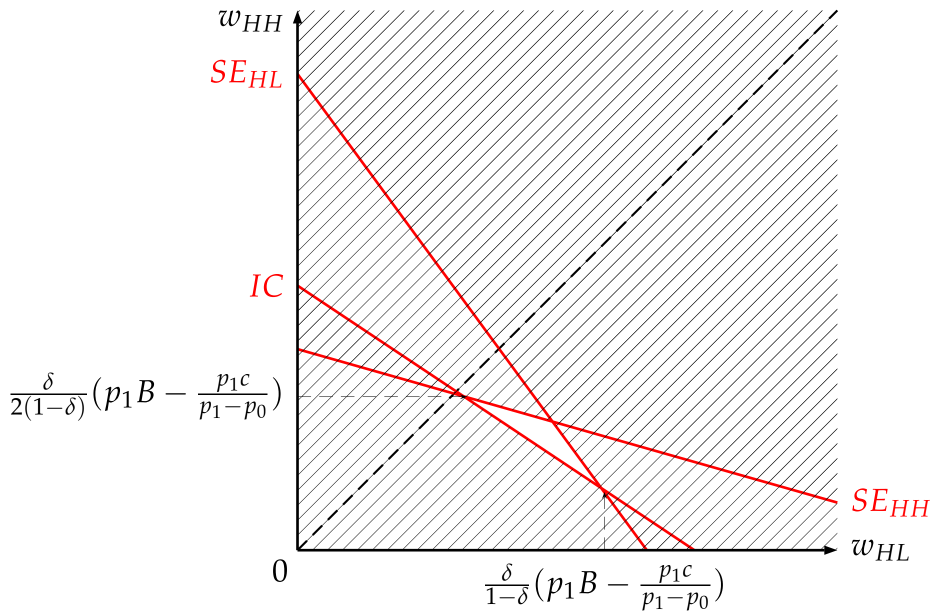

Figure 2: Principal's commitment

HH. The next proposition follows.

Proposition 15. *The commitment problem is more severe for collective bonuses than for relative bonuses.*

While exhibiting an advantage of RPE over CPE, this proposition however does not imply that RPE are always optimal. First, it is possible that the optimal CPE scheme be self-enforcing while the optimal RPE scheme is not. Second, the incentive scheme that is the most robust to the commitment problem is not a pure RPE. To make those two points, let us inquire into the severity of the commitment problem by varying the discount factor δ. For high values of δ, the principal cares enough about future profits to credibly promise high bonuses. The commitment problem has no bite. As δ decreases, the set of self-enforcing incentive schemes shrinks. Whether the optimal (pure) CPE or (pure) RPE becomes first unfeasible depends on the value of p_1. To see this, note that the bonuses of optimal RPE and CPE schemes, $w_{HL} = \frac{c}{(1-p_1)(p_1-p_0)}$ and $w_{HH} = \frac{c}{p_1(p_1-p_0)}$, respectively, only differ with respect to p_1. The higher p_1, the greater the required competitive bonus relative to the collective bonus. Intuitively, if p_1 is high, it requires a high reward to make agents work under a competitive scheme as they are likely to both succeed and earn 0. Therefore, a large p_1 makes it more likely that self-enforcement constraints rule out

RPE schemes. Formally, if $p_1 \geq \frac{2}{3}$, then as the value δ decreases, the optimal RPE scheme is the first scheme to violate the self-enforcement constraint. On the contrary, if $p_1 \leq \frac{2}{3}$, the first incentive scheme to violate the self-enforcement constraint is the optimal CPE scheme.

Now, consider the value of δ for which only one incentive scheme remains feasible. The induced bonuses make the two upper bounds (as well as the incentive constraint) binding which implies that $2w_{HH} = w_{HL}$. This contract then is a mixed RPE scheme, that can be thought of as a combination of an individual bonus and a relative bonus. Intuitively, the contract that is the most robust to the commitment problem is the one that spreads aggregate payments uniformly across the states HH, HL and LH.

5.3 Agents' Commitment

We now turn to commitment issues on the agents' side. This can be an issue for instance in the case of imperfect property rights enforcement. Suppose that the agents are software developers in a firm, and that they can walk away with the key parts of a new software and sell them to a competing firm. If the software of an agent turns out to be a success, the incentives to try to market it independently of the initial firm can be quite substantial. Kvaløy and Olsen (2012) show in the repeated interaction setting of Che and Yoo (2001) that if agents can leave the firm at any period with a share of the surplus, then independent schemes gain value compared to dependent schemes (recall that in Che and Yoo (2001), CPE schemes were optimal).[44] We bring this idea in our simple static setting to illustrate this point. We allow arbitrary technological and informational links between the agents, so that agents' efforts can be either complement or substitutes. We just add the possibility that each agent leaves the firm after having observed the pair of results, selling (part of) his own output on the market. We assume that an output L has no value, and that by selling an output H, the agent earns s. Assume that the principal has never interest in letting an agent sell his output, even when s is high. In the software example, this means that the firm has a higher valuation for the software that what the agents could obtain on the external market, which could be the case for compatibility reasons or competitive motives.

A purely dependent scheme makes a successful agent earn nothing in some state

[44] Meyer (1995) also shows that in a two-period setting, independent performance evaluation can be optimal even though either collective or relative schemes are optimal in a one-period model. This comes from a the ratchet-effect: Agents' ability is initially unknown, but partially revealed by first-period performance, which itself is used to calibrate second-period incentives. Hence it is a mix of agents' and principal's commitment problem that makes independent schemes appealing in that case. See also Meyer and Vickers (1997) for a related and richer analysis.

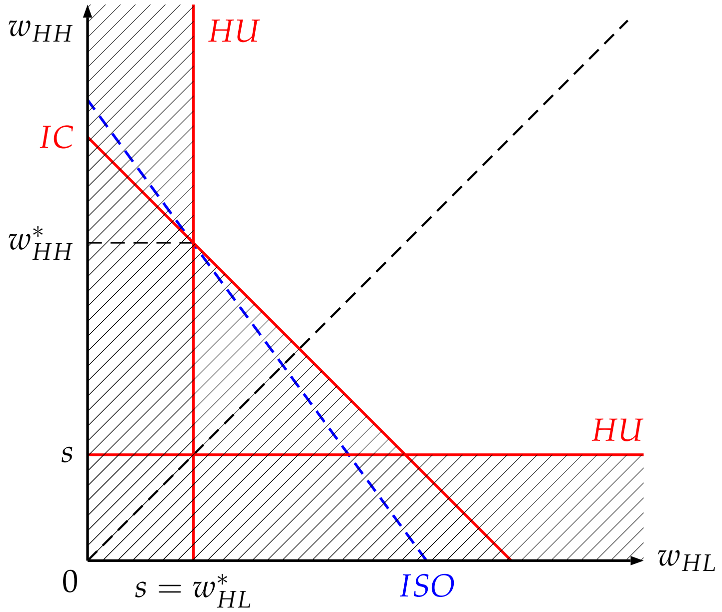

Figure 3: Agent's commitment: the case of complementary efforts.

of nature. More precisely, in a pure RPE scheme, an agent is not entitled to a bonus if the other agent also succeeds. In a pure CPE scheme he cannot earn a bonus if the other agent fails. Since the agent can always earn s when successful, the principal must provide a bonus of at least s when the agent is successful. Formally, two new constraints are added to the principal's problem: $w_{HH}, w_{HL} \geq s$.

They corresponds to ex-post participation constraints of the agent, or alternatively renegotiation proofness on the agent's side. Compared to previous CPE and RPE schemes, this amounts to imposing a minimal independent bonus to the incentive scheme. This does not affect the incentive efficiency of the bonuses, hence it is still optimal to set the less efficient bonus at the minimum level. The higher bonus is obtained by making the incentive constraint bind, i.e. the incentive weight has to be smoothed over the two bonuses, at the cost of a higher expected compensation. The scope for dependent scheme shrinks as s increases because the most extreme schemes are not feasible anymore, to the point that for very high s, the scheme boils down to an independent scheme.

Proposition 16. *When agents can appropriate part of the ex-post surplus, the scope for dependent schemes is reduced. When this hold-up concern is strong enough, the only feasible incentive scheme is IPE.*

Table 3: Factors affecting the choice of team incentives

	RELATIVE	INDEPENDENT	COLLECTIVE
PRODUCTION	Substitutability	Independence	Complementarity Help and sabotage
INFORMATION	Positive correlation	Independence	Negative correlation Mutual monitoring
AGENTS' RELATIONSHIP			Transfers feasible Peer pressure Repeated interaction
BEHAVIORAL	Status-seeking preferences Self-overconfidence		Inequity aversion Overconfidence in others
COMMITMENT ISSUES	Multilateral relationship Principal's moral hazard	Agents' side	

6 Conclusion

It is now well established among researchers and practitioners that contracting with several agents makes it profitable to make one's remuneration conditional on another's result. We have seen how dependent incentive schemes take advantage of a variety of specificities of the task to be performed. Our simple model makes it possible to organize the numerous findings from agency theory, thus drawing a broad picture of the mapping from those specificities to the relative worthiness of collective and relative incentive schemes. This section briefly reviews those results and proposes avenues for future research. The basic principles are summarized in table 3.

The most immediate principle underlying the choice of an incentive scheme is that it must exploit interdependences between agents' tasks. Interdependences in the production process can take the form of positive or negative externalities of one agent's effort on the other's result. As an example, consider two agents selling two different products for the same company. Positive externalities arise if the products are complementary, while substitutability of products induces negative externalities. Quite intuitively, efficiency requires that incentives make agents internalize those externalities, which is obtained though collective incentives in the former case and competitive incentives in the latter. Interdependences in the production process also stems from actions that an agent can undertake to directly affect the other's result. The two sellers could for instance advertise for the other's product, or on the contrary advise clients not to buy it. If it is beneficial for the company to induce help among agents or to deter sabotage, then incentives should be collective in order to align agents interests. Note that help activities can cover many different forms of interactions: an interesting application is suggested by Hamilton, Nickerson and Owan (2003) who reports aggregate gains in productivity after the introduction of collective incentives and suspect that they are partially due to skill sharing from high ability workers to low ability workers.

Another important form of interdependence arises when one agent's result provides information on another agent's effort. Such informational dependences may arise from unobservable (or at least not perfectly observable) random shocks affecting all agents' results. Traders whose results are affected by the same aggregate market conditions constitute a classical example. In conformity with the Informativeness Principle (sufficient statistics result) of Holmström (1979), these informational dependences ought to be exploited in incentive contracts by indexing one agent's remuneration on the result of others. Whether the resulting dependent schemes are competitive or collective depends upon the sign of the correlation of results. With positive correlation, as in the traders' example, this calls for competitive incentives, while with negative correlation, this calls for collective incentives. Informational dependences have often been invoked as a reason for the existence of tournaments as incentive device, since tournaments are a particular instance of competitive incentive schemes (Green and Stokey, 1983; Nalebuff and Stiglitz, 1983; Mookherjee, 1984). Since this argument applies to any kind of competitive incentive scheme, it is not clear yet why this specific type of competitive scheme that only uses partial (ordinal) information should be so pervasive.[45] We feel that there remain some open issues to capture formally the value of tournaments, as we hint in our original modeling of this issue, in relation to the insight put forth by Lazear and Rosen (1981): comparing results is easier than evaluating them in absolute terms.

Yet another different form of interdependence comes from agents having social preferences (i.e. not purely selfish traditional rationality). Agents being concerned about their payments relative to other agents' creates externalities similar to technological externalities. On the one hand, status-seeking agents, for instance, are incited by ex-post differences in wages, and thus relative schemes are adapted to them. On the other hand, if agents exhibit a strong taste for equity, collective incentives are in order. The literature here is still at an early stage in terms of theoretical foundations, and much experimental work is currently dedicated to this issue.

As dependent schemes create strategic externalities between agents' efforts, they may in turn make it worth for

[45] An additional argument for tournaments is their robustness to the principal's commitment problem (Malcomson, 1984).

agents to choose their efforts cooperatively. Indeed, doing so allows them to internalize the strategic externality created by a dependent scheme, and as a consequence to reach higher payoffs. Competitive schemes are most likely to be gamed by agents if they coordinate to reduce the negative externality implied by competition–much in the same way as rival firms may be tempted by market collusion. But agents' cooperation can also enhance the efficiency of collective incentives (Ramakrishnan and Thakor, 1991; Itoh, 1992). How much collusion/induced cooperation harms/increases incentive provision depends on the extent to which agents can closely cooperate, which in turn depends the organization of work. In particular an integrated organization of work tend to ease the capacity of agents to make joint decisions. Critically, the fact that agents be able to monitor each other considerably affects the way incentives should be provided (see Harbring, 2006, for a corresponding experimental study). If agents cannot engage in mutual monitoring, then the only way they can improve their payments is by contracting on ex post transfers of bonus. Under such collusive behavior, the principal cannot be better off as agents just game the scheme. As we pointed out, a complete theoretical treatment of optimal incentive provision under collusion has yet to be done. On the other hand, if the organization of work induces agents to observe each others' efforts, then agents should be able to reach higher degree of cooperation, i.e. jointly choose their efforts level. This coalitional behavior can be enforced either by a contract in which case full cooperation is reached, or through reputation-type mechanisms, in which case the degree of cooperation increases with the weight of the value of the future interactions among agents. Agents' mutual monitoring ability can then generate gains for the principal through the use of collective incentives (Ramakrishnan and Thakor, 1991; Holmström and Milgrom, 1991; Che and Yoo, 2001).

Note that peer pressure as defined by Kandel and Lazear (1992) is an alternative cooperation enforcement device, as agents are assumed to be willing to punish each other in case of deviation. While we have focused on cooperation being enforced through "selfish" concerns, the importance of social pressure must not be underrated: Mas and Moretti (2009) are able to identify peer pressure emerging without any financial motivation for collective performance. Falk and Ichino (2006) document "pure" peer effects in a real-effort experiment. With respect to social preferences, an interesting finding is due to Hamilton, Nickerson and Owan (2003), who document that highly productive workers are willing to join teams at the cost of a decreased remuneration. This suggests either concerns for social prestige or enjoyment of team work resulting in their participation constraint being relaxed. However, Guryan, Kroft and Notowidigdo (2009) on the contrary find no evidence of peer effects in professional golf tournaments. As they suggest, this finding may be due to the fact that unlike the aforementioned studies, professional golf players receive extremely high powered incentives which may reduce the scope for social concerns. They also propose that golf professional competitors are a very particular population that may be less susceptible to be influenced. Evaluating to what extent social peer effects matter and what characteristics of the professional environment make them likely to appear constitutes an exciting challenge for future empirical works.

It is well appreciated that in many situations the provision of incentives is constrained by additional contractual frictions. A first issue relates to the possibility of ex post hold-up from one of the parties which constrains incentives differently whether it comes from the principal or the agents. If agents can threaten to leave the firm with a share of their output, then this forces the incentive scheme to provide a bonus at least equal to the share the agents could extract. This reduces the scope for dependent incentive schemes (Kvaløy and Olsen, 2012). Hold-up from the principal matters when the contingencies on which the incentives are based are not verifiable in courts: in this case the principal can not credibly commit to pay the bonuses specified in the contract if they are too high. This issue is at the center of the literature on subjective evaluations where the principal provides rewards contingent on his personal evaluation of the result (MacLeod, 2003). Competitive schemes are proved to be more robust to this commitment issue. In particular, tournaments help overcoming the problem by making payments contingent solely on the ranking of agents, which makes the total amount paid by the principal independent of his evaluation. It must be noted that the argument relies on the principal being able to commit to transfer some fixed aggregate bonus. If this is not possible, then the principal's commitment problem can only be mitigated in repeated relationships by reputation-type mechanisms (Levin, 2003). The fear of losing the continuation value of the relationship makes incentives credible as long as bonuses are not too high. In a multi-agent setting, this additional limited liability constraint applies to the sum of agents bonuses if all agents threat to break the relationship following a deviation with any one of them. It turns out that this additional flexibility is often better exploited through competitive schemes as they permit more smoothing of payments across outcomes.

Another related constraint on the provision of incentives occurs when the principal can exert a costly (unobserved) effort that affects the productivity of his agents (Al-Najjar, 1997; Gupta and Romano, 1998). The problem of the principal is that his and the agents' incentives are antagonistic as both parties must be rewarded following high results. The best way of mitigating this problem turns out to use competitive incentives, introducing a tension between agents, and between the principal and the agents in the following sense: agents receive a bonus only when one of them obtains a high result while the principal is rewarded in the sense of not paying bonuses when both agents succeeds.

Most of the mechanisms identified in the Agency literature either favor pure competitive or collective schemes. But real-life examples abound in which the provision of incentives is mixed: for example, most employees are motivated through stock participation or divisional bonuses, a form of collective incentive, and through promotions, a relative incentive. Surprisingly, this has been by and large neglected in the theoretical literature.[46] We believe that understanding the use and properties of mixed schemes, and uncovering the reasons why they can constitute optimal incentive contract is an important research question, for incentive theory, applied work and practitioners at the same time.

[46] Carmichael (1983) recognized early that absolute and relative evaluation are often simultaneously used in practice–e.g. "salesmen who work on commission and also compete for Hawaiian vacations" (Carmichael, 1983, p. 50), and that the mix deserved attention. The choice of stick vs carrots has been studied a lot, including in the tournaments literature (see e.g. Moldovanu and Sela, 2001; Moldovanu, Sela and Shi, 2012), but not the optimal mix of collective and relative incentives. See however Magill and Quinzii (2006) and Fleckinger (2012) who show that general forms of informational dependence can generate optimal incentive contracts mixing collective and competitive rewards.

A Omitted proofs

A.1 Proof of Lemma 1

In the principal's program, let $\lambda > 0$ be the Lagrange multiplier associated with the incentive constraint, and $\mu_{\mathbf{R}} \geq 0$ that associated with the limited liability constraint $w_{\mathbf{R}} \geq 0$. The first-order conditions for each $w_{\mathbf{R}}$ is:

$$- Prob(\mathbf{R}|1,1) + \lambda(Prob(\mathbf{R}|1,1) - Prob(\mathbf{R}|0,1)) + \mu_{\mathbf{R}} = 0.$$

If a wage $w_{\mathbf{R}}$ is positive then $\mu_{\mathbf{R}} = 0$ and the last equation writes:

$$I(\mathbf{R}) = \frac{1}{\lambda}.$$

For a wage equal to zero, say $w_{\mathbf{R'}}$, one has $I(\mathbf{R'}) = \frac{1}{\lambda}(1 - \frac{\mu_{\mathbf{R'}}}{Prob(\mathbf{R'}|1,1)}) < \frac{1}{\lambda}$, hence the conclusion.

A.2 Proof of Proposition 9

The following mechanism approximates the First-best with unique implementation when agent's monitor each other. Let us denote by $m_i \in \{0,1\}$ the message of agent i regarding the effort of agent $-i$. That is, $m_i = e_{-i}$ correspond to truth-telling. Consider the following transfers conditional on messages and outcomes:

$$t_i(HH, m_i, m_{-i}) = m_{-i}(c + \varepsilon) - m_i\alpha + m_i\beta$$
$$t_i(HL, m_i, m_{-i}) = m_{-i}(c + \varepsilon) - m_i\alpha + \beta$$
$$t_i(LH, m_i, m_{-i}) = m_{-i}c$$
$$t_i(LL, m_i, m_{-i}) = m_{-i}c$$

with $0 < p_0\beta < \alpha < p_1\beta$ and $\varepsilon > 0$, and those three numbers chosen arbitrarily small. The role of (α, β) is to induce whistle-blowing, while ε makes (e_i, e_{-i}) a unique equilibrium strategy in the first stage.

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