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Mutual Monitoring versus Incentive Pay in Teams

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Abstract

In a principal - multi-agent relationship, we derive the optimal mutual monitoring - incentive pay mix. When the agents are better informed about their effort choices than the principal, and when their information is sufficiently "good" there is a substituability between those two modes of providing incentives. However we show that the optimal mix depends on agents' liability limit. When it is sufficiently slack the principal uses stronger incentive pay and less mutual monitoring. We also derive the conditions for adoption of costly mutual monitoring technology.

Résumé

Dans une relation - principal multi-agents, on étudie le dosage optimal entre incitations monétaires et supervision par les pairs. Lorsque les agents sont mieux informés sur leurs efforts que le principal, et lorsque leur information est de "bonne" qualité, il existe de la substituabilité entre ces deux modes d'incitation. Cependant on montre que le dosage optimal dépend du degré auquel les agents sont protégés par la clause de responsabilité limitée. Lorsque leur dotation est suffisamment élevée le principal privilégie les incitations monétaires et a un recours moindre à la supervision mutuelle. On étudie également les conditions d'adoption d'une technologie de supervision mutuelle coûteuse.

Keywords : Principal - Multi-agents, Side contracting, Mutual Monitoring

JEL classification : L2, J31, J33

1 Introduction

Since the early nineties widespread transformations of work organization have been observed. A large range of firms have shifted to the adoption of employee involvement practices. Osterman (1995), among others, points out[1] increasing adoption by American firms of self managed teams, quality programs, job rotation.

An appealing argument in favor of team work adoption is that workers are better informed about the best way to organize the productive process and thus could be a source of continuous improvement. However to achieve such improvement the agents should be given the adequate discretion and incentives. Appelbaum and Batt (1994) observe that the adequate incentives are provided by ensuring employees participation in setting human resources policies: self managed teams are setting disciplinary rules governing appropriate behaviour on the job, they help in the selection of new entrants in the team, they could even be responsible for "developing and administering policies regarding absenteeism and the replacement of absent workers".
The phenomenon of monitoring delegation to team members is also related by sociologists. Smith (1997) presents the following conclusions on self-managed teams:

> "Team-based production methods represent a new, more decentralized, and less visible tactic of control. Monitoring, evaluation and disciplinary actions moves down the hierarchy from the hands of supervisors and diffuses into the hands of team mates."

Finally recent empirical studies emphasize the existence of strong complementarities in the adoption of certain human resources practices. Ichniowski, Prennushi and Shaw (1997) and Boning, Ichniowski and Shaw (2003) show that the adoption of team work improves productivity when it is accompanied by: frequent interactions between team members, empowerment for solving day to day problems, improving of mutual monitoring between employees, group remuneration schemes.

[1] In a study based on 875 American firms

It appears that to foster productivity, when adopting team work, it has to be accompanied by the adoption of human resources management practices improving cooperation and mutual supervision between employees. The traditional analysis of team work, initialized by Holmström (1982), emphasizes the existence of a free riding problem, which raises the incentive cost of the principal. In this article we consider an additional way of providing incentives inside a team. We assume that employees are able to coordinate their effort choices through informal relationship. Thus we develop a framework where risk neutral, liability constrained agents, contract on signals contingent on each other's effort choice and observable only inside the team. The employees are contracting on a compensation transfer and a punishment scheme. As agents are subject to a limited liability constraint to make the transfer possible the principal has to abandon part of his punishing capacity. The remuneration scheme proposed by the principal influences both the acceptability, the credibility[2] and the type of the side contract that will be adopted.
When agents are side contracting the principal's benefit is a reduction of the incentive bonus, the cost to pay is an increase of the fixed wage. We study the conditions under which authorizing side contracting is beneficial for the employer, and when it will be in his interest to implement costly procedures of mutual supervision. We characterize the optimal mutual monitoring incentive pay mix and emphasize the impact of the liability limit on the choice of the incentive scheme.

We can distinguish two main ways the cooperation between agents have been treated in the existing literature. First cooperation can be viewed as the possibility for an agent to help his colleague in accomplishing a task, the relevant questions being that of the corresponding incentive scheme and of the optimal choice of task clustering between employees (see Itoh (1991), Macho-Stadler and Perez-Castrillo (1993) among others).

[2] The idea is that the agents are not able to credibly commit on transfers not respecting their liability limit.

A second strand in the literature, closer to our work, considers cooperation through the agents' possibility to side-contract on their action choices. Holsmtröm and Milgrom (1990) and Itoh (1993) show that the principal benefits from letting the agents side contract on their effort choices, when they can perfectly observe each other's effort[3]. In this case from the principal's point of view everything happens, as if he was contracting with a consolidated unit, whose utility is the sum of it's members utilities, thus the employees can monitor each other's effort and coordinate their actions. As the agents are risk averse there is an additional - re-insurance effect, of side contracting. We consider the case of imperfect information about efforts and risk neutral agents. The agents' utilities are not perfectly transferable and as the transfers guaranteeing the incentive compatibility of the side contract are subject to a limited liability constraint, we discuss the existing link between the incentives provided by the principal and those resulting of the employees' arrangement.

Finally our work is closely related to a strand of the literature, initialized by Kandel and Lazear (1992). Who explicitly consider the disutility effect of peer pressure without addressing the question of its endogenous formation.

In section 2 we present the framework and a benchmark of individually incentive scheme. In section 3 we present the coordination agreement and derive the characteristics of the optimal mutual monitoring incentive pay mix. In section 4 we extend the model to the case of costly mutual monitoring technology and compare two organizational structures. Section 5 concludes. All proofs are in the appendix.

[3]Arnott and Stiglitz (1991) and Laffont and Rey (2001) provide similar results in the cases respectively of insurance and micro-finance.

2 The Model

2.1 Framework

A manager (principal) is contracting with two identical employees (agents), for the realization of a project. All parties are risk neutral. However we assume that the agents are subject to limited liability[4], the transfers they receive must always be greater than or equal to some exogenous level: $-M$, where $M \geq 0$. Each agent can exert a costly effort e_i, $i \in \{1, 2\}$. Two possible values can be taken by e_i, which we normalize as follows: $e_i = \{0, 1\}$, i.e. the agent can either "work" or "shirk". Exerting effort is a source of disutility for the employees: $c(0) = 0$ and $c(1) = c$. The principal observes the total production level y, which can only take two values $\{y^L, y^H\}$, with $y^H > y^L$. As output level is the unique contractible, the payments will be contingent on its realization: $w_i = \{w_i(y^H); w_i(y^L)\} = \{{w_i}^H; {w_i}^L\}$, with $\Delta w = w^H - w^L$. The stochastic influence of effort on y is characterized by the probabilities: $Pr(y = y^H / e_1 = i, e_2 = j) = p_{e_i e_j}$.

Assumption 1. *We make the following assumptions about the probability function:*

- $1 > p_{11} > p_{01} = p_{10} > p_{00} \equiv 0$
- $p_{11} - p_{01} > p_{10} - p_{00} \Leftrightarrow p_{11} > 2p_{01}$

The probability of high production is increasing in effort[5]. Furthermore we assume a strategic complementarity in employees' efforts: when one of the agents works the marginal productivity of the other agent's effort is increased[6].

To simplify the analysis, we also assume that the higher effort realization is sufficiently valuable for the principal, so it is always profitable to induce the agents

[4]The Limited Liability assumption, can be justified by the possibility for each of the agents to quit the company in case of excessive monetary pressure. Another interpretation is to consider that the agents are extremely risk averse above a certain threshold.

[5]The assumption of $p_{00} \equiv 0$, does not affect qualitatively our results.

[6]The equivalent assumption in a case with a continuum of effort levels: $\frac{\partial^2 p(e_i, e_j)}{\partial e_i \partial e_j} > 0$.

to work. Thus we will focus on the reduced principal's problem, which is to minimize the expected cost for implementing the high effort choice for both agents.

In the traditional analysis the agents' incentives are provided by the wage scheme proposed by the principal to each of them. However as mentioned earlier leaving some discretion to employees in setting human resources policies may affect team productivity. We begin our analysis by the case of individually incentive contracts and then consider a possibility for the agents to coordinate their effort choices via a side contract.

2.2 Individually Incentive Contracts

Let us begin the analysis by presenting a useful benchmark of individually incentive contracts. The unique source of incentives for the agents is the wage scheme proposed by the principal to each of them. The manager's program writes as follows:

$$\min_{w^H, w^L} 2(p_{11}w^H + (1-p_{11})w^L) \Leftrightarrow \min_{\Delta w, w^L} 2(p_{11}\Delta w + w^L)$$

under the constraints:

$$\begin{cases} p_{11}\Delta w + w^L - c \geq p_{01}\Delta w + w^L & (IC) \\ p_{11}\Delta w + w^L - c \geq \bar{U} & (IR) \\ w^L \geq -M & (LL) \\ w^H \geq -M & (LL) \end{cases}$$

Thereafter the agent's outside option $(\bar{U})$ is normalized to 0.

The optimal contract[7] resulting from the resolution of this program is:

- $\Delta w = \dfrac{c}{p_{11} - p_{01}}$

[7] It is easy to show that with the remuneration scheme presented below and under the assumption of effort complementarity, there are two possible equilibria: $(1;1)$ and $(0;0)$. The equilibrium selection not being the main point of our paper we assume that the agents' choices will converge on the Pareto dominant equilibrium which is the high effort one.

- $w^L = \max\{-M; c - p_{11}\Delta w\}$

As long as the limited liability constraint is sufficiently slack the principal can implement the first best. It will be the case for $M \geq \frac{cp_{01}}{p_{11} - p_{01}}$. We will concentrate our analysis on the case of binding limited liability constraint, and second best contracts. So throughout, we assume that $M < \frac{cp_{01}}{p_{11} - p_{01}}$.

Hence the optimal contract is $(\Delta w = \frac{c}{p_{11} - p_{01}}; w^L = -M)$, and the principal implements the high effort equilibrium at the following expected cost:
$C = 2(\frac{cp_{11}}{p_{11} - p_{01}} - M)$.

As individual remuneration is based on the group output realization, there is a free riding problem, which raises the incentive cost for the principal. In fact the bonus used to motivate an agent to work simply confers a positive externality to his teammate without improving the latter's incentives to exert effort. According to the agents the possibility to coordinate their effort choices can be a possible solution for the internalization of the existing externality.

3 The Coordination

In this section we consider the case of exogenous information technology. Physical proximity between together working agents, close technological relation between their tasks, job rotation, these characteristics of team work, allow us to consider that employees are better informed about their colleagues' actions than the manager.
We assume that team members publicly observe stochastic signals $s_i = \{0; 1\}$ about each one effort choice. The probability of realization of s_i is contingent on agent's i effort. We note the corresponding probabilities as follows: $\Pr(s = 0/e = 0) = q$ and $\Pr(s = 0/e = 1) = r$, with $q > r$. Thus $s = 0$ will be considered as a "bad" signal if the agents decide to coordinate on high effort.

3.1 Presentation

The agents are able to side contract on all the observables (i.e. the signals, and the output) and we assume that their arrangement is enforceable[8]. The terms of this contract are fixing the effort pair, the transfer t and the punishment scheme, maximizing the joint utility function of the team members, in the limits imposed by the grand contract proposed by the principal.

A transfer t, payed by an agent to his team-mate, generates a private benefit λt for the latter, with $\lambda \in [0;1]$. The punishment an employee has to incur, is not always beneficial for his colleague. This imperfection of the coordination technology coupled to the possibility to observe a "bad" signal even if the agent has chosen a high effort level generates a cost of side contracting.

Timing of the game:

t=0 The principal proposes the grand contract to the agents $(w^H; w^L)$.

t=1 Each agent accepts or refuses. If one of them refuses, the game ends.

t=2 The agents decide to sign or not a side contract. If one of them refuses, both are acting non cooperatively, in conformity with the terms of the grand contract.

t=3 Efforts are chosen, the output and the signals observed and the contract(s) executed.

The side contract: The coordination agreement on $(1;1)$ has to maximize the agents' joint utility[9] under the following constraints:

[8]The enforcement of side contracts is relying on non judicial mechanisms, such as reputational devices, dynamic relations with possible trigger. We are adopting here an approach of exogenously given, enforcement mechanism. Che and Yoo (2001) address the question of endogenous enforcement of between agents relationships by introducing long-term interactions.

[9]We show in the appendix 6.3 that coordination on $(1;1)$ is the best the agents can do.

$$\begin{cases} p_{11}\Delta w + w^L - c - \underline{\alpha} t \geq p_{00}\Delta w + w^L & \text{(CIR)} \\ p_{11}\Delta w + w^L - c - \underline{\alpha} t \geq p_{01}\Delta w + w^L - \overline{\alpha} t & \text{(CIC)} \\ t \leq M + w^L & \text{(LL)} \end{cases} \quad \text{(A)}$$

where $\underline{\alpha}$ ($\overline{\alpha}$) is the expected probability[10] net of coordination cost for a working (shirking) agent to pay t. To fix the ideas: if each employee is punished (pays t) in case of bad signal realization independently of the other's signal, we have: $\underline{\alpha} = r(1-\lambda)$ and $\overline{\alpha} = q - \lambda r$.

The participation to the side contract constraint (CIR): a coordination agreement is accepted only if the expected utility of doing so, exceeds what each of the agents can expect, when acting non cooperatively, in conformity with the grand contract.

The coordination between agents could be relevant[11] for $\frac{c}{p_{11}} \leq \Delta w < \frac{c}{p_{11} - p_{01}}$. Actually for these values of the incentive bonus the jointly profitable equilibrium is $(1;1)$, whereas (under the assumption of effort complementarity) the unique non cooperative equilibrium is $(0;0)$. Thus agents' utility in the latter case is their outside option if they fail to side-contract.

Coordinating on the high effort equilibrium is collectively optimal for all $\Delta w \geq \frac{c}{p_{11}}$, if there is no cost to side contract. However the existence of coordination cost will limit the set of Δw, for which coordination on $(1;1)$ will occur.

The incentive compatibility constraint (CIC): since agents are side contracting on signals that reflect only imperfectly their effort choices, there is a moral hazard problem inside the coalition. For a given value of Δw, the side contract will be incentive compatible, if the punishment is sufficiently high to prevent any unilateral deviation.

Finally the limited liability constraint: the transfer t guaranteeing the agents

[10] $\underline{\alpha}$ and $\overline{\alpha}$ are some linear combinations of r, q, λ, p_{11} and p_{01}, conditionally on the punishment scheme adopted by the agents.

[11] If $\Delta w \geq \frac{c}{p_{11} - p_{01}}$, the grand contract is individually incentive, so each agent is exerting the high effort level $e = 1$. If $\Delta w \leq \frac{c}{p_{11}}$, the individual and collective choice are $(0;0)$.

coordination on high efforts, added to the monetary pressure exercised by the principal ($-w^L$) must not exceed M. To make the side contract possible the principal has to raise w^L, to slacken the limited liability constraint. This is the cost to pay for enjoying the potential benefits of the agents' coordination.

3.2 The mutual monitoring, incentive pay mix

The possibility for the agents to side contract on informative signals, is an alternative way of providing incentives. An agent is choosing the high effort, both to increase the probability of receiving Δw, and to decrease the probability of paying the transfer t. Anticipating this possible coordination, the principal will structure the grand contract in a way guaranteeing him the lowest cost for implementing the high effort equilibrium. The principal:

- chooses the type of the grand contract - individually incentive or coordination improving;
- in case of profitable coordination decides and designs the optimal mutual monitoring, incentive pay mix.

Before analyzing the profitability of the coordination agreement for the principal, and the definition of the optimal mutual monitoring, incentive pay mix, we characterize the side contract that will be adopted. We show that by constraining the transfer the agents are able to commit on, the principal constrains the set of punishment schemes.

Lemma 1. *The best side contracting agreement, from the principal's point of view is the one with the largerst* $(\overline{\alpha} - \underline{\alpha})$. *Furthermore the agents are constrained to coordinate through the side contract with the larger* $(\overline{\alpha} - \underline{\alpha})$.

Relaxing the limited liability constraint of the agents is costly, thus the principal is better off when for a given value of t he obtains the larger possible reduction of the incentive bonus.

Lemma 2. *The side contracting agreement preferred by the principal (and adopted by the agents) is as follows: each agent is punished (pays the transfer to his colleague) in case of bad signal, regardless of the realization of his team mate's signal or of the whole output.*

The coordination stage: When applying Lemma 2, (A) writes:

$$\begin{cases} p_{11}\Delta w - c - r(1-\lambda)t \geq 0 & (CIR) \\ (p_{11} - p_{01})\Delta w - c - (q-r)t \geq 0 & (CIC) \\ t \leq M + w^L & (LL) \end{cases}$$

The cost of coordination being proportional to t, it is in the agents' interest to fix the minimal value for the transfer guaranteeing the effort incentive compatibility of the side contract. So from (CIC) we have $t = \dfrac{c - (p_{11} - p_{01})\Delta w}{q - r}$.
This equation makes clearly appear the substituability between Δw and t. When the principal reduces the bonus, he implicitly delegates the charge of coordination to the agents. Lower Δw means that to reach the high effort equilibrium, the agents have to fix higher t. However the maximal acceptable amount of the transfer (a fortiori the minimal amount for Δw) is limited. First, because agents are protected by the limited liability constraint $t \leq M + w^L$. Second, raising t raises the cost of coordination and makes the side contract less attractive for the agents. Thus the (CIR) constraint introduces a second upper bound on t: $t \leq \dfrac{p_{11}\Delta w - c}{r(1-\lambda)}$.

The grand contract: The principal's reduced program writes:

$$\min_{\Delta w, w^L} 2(p_{11}\Delta w + w^L)$$

under the constraints

$$\begin{cases} \Delta w \geq \dfrac{c-(q-r)(M+w^L)}{p_{11}-p_{01}} & (1) \\ \Delta w \geq \dfrac{c(q-\lambda r)}{p_{11}(q-\lambda r)-p_{01}(r-\lambda r)} & (2) \\ w_L \geq -M & (3) \\ p_{11}\Delta w + w^L - c - (r-\lambda r)\dfrac{c-(p_{11}-p_{01})\Delta w}{(q-r)} \geq 0 & (4) \end{cases}$$

The first constraint gives us the link between the reduction of the incentive bonus and the fixed wage proposed in the grand contract - to reduce the Δw the principal has to raise w_L. The right term of the second one corresponds to the maximal reduction of the incentive bonus that can be achieved by authorizing the coordination inside the team. If the employer proposes a contract with Δw, below this value, it is impossible for the agents to commit on side transfers guaranteeing, both the incentive compatibility and the acceptability of the coordination agreement. Thus in the cases, the principal implements the high effort equilibrium, with this minimal incentive bonus, we consider that the coordination ability of the side contract is fully used. Equations (3) and (4) are the limited liability and the participation to the grand contract constraints.

The terms of the optimal contract from the principal's point of view will depend on the informativeness of the signals and the liability limit of the agents.

Proposition 1. ***Low informativeness of the signals***
If $q-r \leq \dfrac{p_{11}-p_{01}}{p_{11}}$*, the optimal contract is the individually incentive one:* $\left(\Delta w = \dfrac{c}{p_{11}-p_{01}}; w_L = -M\right)$.

The benefit for the principal of the coordination capacity of the agents is a reduction in the incentive bonus, at the other side to make the coordination possible the manager has to raise w^L, which will raise the expected cost of implementing high effort. In the case of low informativeness of the signal the marginal gain of the coordination is lower than the marginal cost of making it possible. So the optimal contract is the individually incentive one.

From the principal's point of view, the side contract is expanding his set of incentive instruments. However as these instruments are interdependent, the principal's optimal choice depends on their relative efficiency.

Proposition 2. ***High informativeness of signals*** *($q - r > \frac{p_{11} - p_{01}}{p_{11}}$)* ***and optimal incentive mix.***

1. *If $M \leq \bar{M}$. The principal proposes the minimal incentive bonus implementing the high effort equilibrium, and fully uses the coordination possibility of the side contract.*

2. *If $M > \bar{M}$. The principal proposes higher incentive bonus, so peer coordination is less requested.*

with $\bar{M} = \dfrac{cp_{01}}{p_{11}(q - \lambda r) - p_{01} r(1 - \lambda)}$

The optimal contract is presented on Figure 1, below.

Authorizing coordination decreases the expected utility of the agents: by decreasing the incentive bonus, and by the coordination cost they are incurring when side-contracting. Thus there are two potential limits on w^L. First, to make the side contract possible the principal has to slacken the limited liability constraint (1) and raise w^L. Second, for a given value of Δw, when setting w_L, the principal has to guarantee the participation of the agents to the grand contract, thus (4) is also constraining w_L.

Let us assume that the principal sets the incentive bonus at its minimal possible level, binding (2).

- For low values of M ($M \leq \bar{M}$), the binding constraint on w_L is (1). Any increase of w^L is intended to make the side transfers possible. As for high informativeness of the signals the benefit of coordination exceeds the cost of

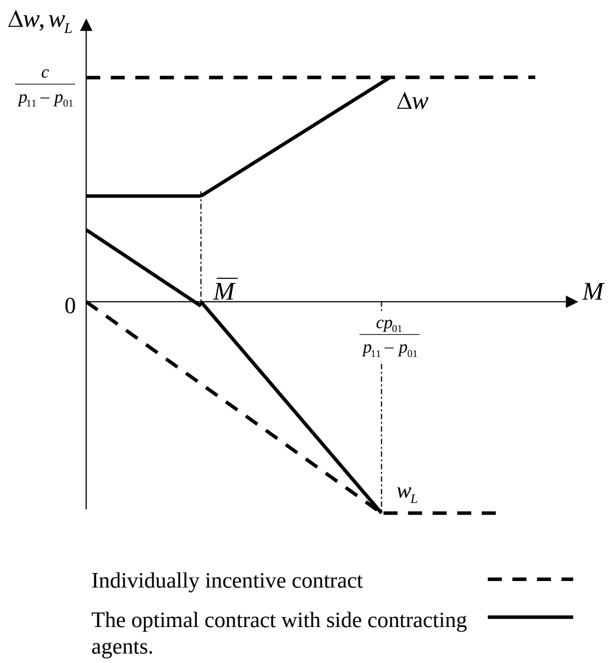

Figure 1: The optimal mutual monitoring, incentive pay mix.

making it possible, delegating the maximal part of coordination to the agents (and thus fixing Δw at its minimal level) is optimal for the principal.

- For $M > \bar{M}$, the principal increases w_L to meet the participation to the grand contract constraint (4). Only part of this increase, is intended to make possible a reduction of the incentive bonus. So the principal will be better off by raising the incentive bonus and using the total punishment capacity given by M.

In Propositions 1 and 2, we show that profitability and optimal mix of different schemes for coordinating agents' actions, depend on: their liability limit, the coordination technology imperfection and the signals' quality.

In general the liability limit of the agents affects the principal's cost of implementing high effort, without modifying the incentive scheme he proposes. In our framework, M conditions the choice of the incentive mix, and for $M > \bar{M}$, it determines the degree at which the principal makes appeal to peer coordination.

The principal's decision between an individually incentive contract or the one with mutual supervision is not affected by $(1 - \lambda)$. However when dead-weight loss raises (low λ), it reduces the set of incentive bonuses for which delegating coordination is possible.
For a given value of M the form of the grand contract will depend on λ. Actually $\bar{M}(\lambda)$ increases with λ. For high values of the coordination cost set of M, for which the principal requests only partial coordination, is expanded.

When employees are better informed about their actions, than the manager, delegating the coordination is profitable for the latter. Adoption of management practices improving observability of effort choices inside the team, could be in the employer's interest (even if the adoption is costly). In the next section we address the question of endogenous adoption of such mutual monitoring technology.

4 Extensions

4.1 Coordination with costly information

The principal has the possibility to implement costly procedures or organizational devices making possible (or improving) the mutual supervision between agents. Such as regular team meetings, problem solving practices and s.o. However the effectiveness of such devices depends on the agents' envy to make the corresponding individual investment (effort), not obviously observable by the principal.
In this section we assume that the principal proposes to the agents a supervision technology. Monitoring requires a costly effort for the agents, noted a and it gives the possibility to observe the other's agent effort with probability ν. The supervisory effort is not verifiable, so the principal cannot contract on it.

Timing:

t=0 The principal proposes the grand contract $(w^H; w^L)$ to the agents, and decides to give them access, or not, to a mutual monitoring technology.

t=1 Each agent accepts or refuses. If one of them refuses the contract, the game is over.

t=2 The agents decide to sign, or not, a side contract.

t=3 Each agent decides to exert, or not, the supervision effort.

t=4 Productive efforts are chosen[12], the output and the signals observed and the contract(s) executed.

This particular timing eliminates the commitment problem on the supervisory effort. If the supervision is exercised ex post, and the agents are not able to commit

[12]Each agent chooses his productive effort after observing the decision of his team-mate at each of the previous stages.

on it: in equilibrium the agents are supposed to work, so doing the supervisory effort ex post is inefficient, the agents anticipate that and the high effort equilibrium is no more sustainable.

The agents are maximizing their joint utility under: the participation to the coordination agreement, the incentive compatibility and the limited liability constraints.

$$\begin{cases} p_{11}\Delta w + w^L - c - a \geq p_{00}\Delta w + w^L & CIR \\ p_{11}\Delta w + w^L - c - a \geq p_{01}\Delta w + w^L - a - t\nu & CIC \\ t \leq M + w^L & LL \end{cases}$$

As the transfer is not affecting the agents' expected utilities on the equilibrium, the limited liability constraint will be bounded. Thus they chose the highest possible sanction, a shirking agent will be charged if detected.

We also observe that as far as supervision is realized before productive effort, if the coordination agreement is acceptable for the agents, than the supervisory effort will be obviously done.

The principal‘s program writes:

$$\max_{\Delta w, w^L} -2(p_{11}\Delta w + w^L)$$

under the constraints:

$$\begin{cases} p_{11}\Delta w - c - a \geq 0 \\ (p_{11} - p_{01})\Delta w - c + (M + w^L)\nu \geq 0 \\ M + w^L \geq 0 \\ p_{11}\Delta w + w^L - c - a \geq 0 \end{cases}$$

The first one is the participation to the side contract constraint. In this case it coincides with the collective incentive constraint[13]. As it was mentioned above the principal is not observing the realization of the supervisory effort. We also have the incentive constraint for respecting the coordination agreement, and the traditional limited liability and participation to the grand contract constraints.

The resolution of the program gives us results very close to those in section (3.2). However as there is a fixed cost of the mutual monitoring technology, it will also be a choice variable in the principal's decision of letting the agents side contract or not.

Proposition 3. *Delegating a part of the coordination to the agents will be beneficial for the principal if and only if the supervisory technology is such that:*

- $\nu \geq \frac{p_{11} - p_{01}}{p_{11}}$
- *If* $M \leq \frac{p_{01}c - a(p_{11} - p_{01})}{p_{11}\nu}$ *the coordination agreement is profitable if:* $a \leq \frac{cp_{01}}{p_{11} - p_{01}}$
- *If* $M > \frac{p_{01}c - a(p_{11} - p_{01})}{p_{11}\nu}$ *the coordination agreement is profitable if:* $a < \frac{cp_{01}}{p_{11} - p_{01}} - M$

Proposition 4. ***Optimal contract with costly mutual monitoring technology*** *When the conditions of the Proposition 3 are satisfied the optimal contract is:*

- $\Delta w = \frac{c + a}{p_{11}}$
- $w^L = \max\{-M + \frac{p_{01}c - a(p_{11} - p_{01})}{p_{11}\nu}; 0\}$

The first condition in Proposition 3, as previously is on the informativeness of the signals observed by the agents. The second condition is on the maximal acceptable level for the supervisory cost. We note that this maximal acceptable level will

[13] The complete constraint writes: $2(p_{11}\Delta w + w^L - c - a) \geq \max\{2(p_{00}\Delta w + w^L); 2(p_{01}\Delta w + w^L) - c - a\}$. It is easy to show that under the assumption of effort complementarity, the strongest constraint is the one appearing in the principal's program above.

depend on the liability limit of the agents. In section 3.2, the cost of coordination is generated by the imperfect coordination technology, and is proportional to the transfer, guaranteeing the incentive character of the side contract. Thus the principal has the possibility for high values of M, to reduce (implicitly) the coordination cost by proposing larger incentive bonus. Here we have a fixed cost of coordination, and the choice of the principal in fine is a binary one - to allow or not the agents' mutual monitoring. So for high values of M, the agent's side contracting with mutual monitoring will be attractive for the principal only for very low values of the supervisory effort. We observe that this values are decreasing with M, and that for $M \to \frac{cp_{01}}{p_{11} - p_{01}}$, the coordination agreement will be profitable only if there exist a free monitoring technology.

4.2 Delegating the supervision to one of the agents

In this section we consider an alternative organizational form, the principal can adopt before proposing the grand contract. Thus he delegates to one of the agents the contractual relationship with his team-mate, and the access to the supervisory technology.

Let us assume, without loss of generality since agents are identical, that the principal delegates these two responsibilities to A_1. The characteristics of the technology are the same as above: the cost of supervisory effort is a, and the agent observes the other's productive effort choice with probability ν. In this section, for simplicity, we consider that the principal can not impose negative wages to the agents, $M \equiv 0$.

Timing in the case of delegation (DS hereafter):

t=0 The principal proposes the contract $(w^H; w^L)$ to A_1, and a supervisory technology $(a; \nu)$.

t=1 A_1 accepts or refuses. If he refuses the game is over.

t=2 If A_1 accepts, he proposes a contract $(t^H; t^L)$ to A_2.

t=3 A_2 accepts or refuses.

t=4 Efforts are chosen[14], and contracts executed.

The contract the principal will propose to A_1, must give to the latter the incentives to exert both the supervisory and the productive effort. But also, to be willing to propose an incentive compatible contract to his team mate rather than being the sole working agent, thus keeping the total incentive bonus.

Conditionally on the supervision effort have been done or not A_1 will propose to A_2, the corresponding incentive contract $(t_H^S; t_L^S)$ or $(t_H^{NS}; t_L^{NS})$.

Proposition 5. ***Optimal contract with delegation:***

1. *If* $a \leq \tilde{a}$
   - *The contract proposed by the principal to* A_1 *is:* $\Delta w = \dfrac{c}{p_{11} - p_{01}} + \dfrac{c}{p_{11} - (1-\nu)p_{01}}$ *and* $w^L = 0$.
   - *The contract proposed by* A_1 *to* A_2*, is:* $t^H = \dfrac{c}{p_{11} - p_{01}(1-\nu)}$ *and* $t^L = 0$.
2. *If* $\tilde{a} < a \leq \bar{a}$
   - *The contract proposed by the principal to* A_1 *is:* $\Delta w = \dfrac{c+a}{p_{11} - p_{01}} + \dfrac{c}{p_{11} - p_{01}(1-\nu)} - \dfrac{c{p_{01}}^2\nu}{(p_{11} - p_{01})^2(p_{11} - p_{01}(1-\nu))}$ *and* $w^L = 0$.
   - *The contract proposed by* A_1 *to* A_2*, is:* $t^H = \dfrac{c}{p_{11} - p_{01}(1-\nu)}$ *and* $t^L = 0$.

with $\tilde{a} = \dfrac{c{p_{01}}^2}{(p_{11} - p_{01})(p_{11} - p_{01}(1-\nu))}$ *and* $\bar{a} = \dfrac{cp_{01}p_{11}}{(p_{11} - p_{01})(p_{11} - p_{01}(1-\nu))}$

A detailed presentation of the incentive program, and the proof of the proposition above, are in the Appendix.

[14] We consider that before choosing his productive effort A_2 observes if the supervisory effort have been done by A_1.

The contract the principal will propose to the supervising agent is depending on the technology cost. Thus for low values of the supervisory cost, supervision is valuable for A_1, independently of his productive effort choice. The principal must only give to the agent the adequate incentives to "work". When the cost of supervision is higher than $\tilde{a}$, supervision is valuable only if it is accompanied by a high effort choice for the supervisor. In this case A_1, will both choose to work and supervise only if the incentive pay proposed by the principal is sufficiently high.

Let us compare those two organizational structures: In the case of mutual supervision (MS hereafter) the principal subsidizes the monitoring effort for both of the agents. When he is empowering only one of them, the supervisor's incentive pay is higher than the one of the MS team members. At the other side the incentive bonus of the supervisee is lower than those of the MS team members. For technologies with low cost of supervision, the latter effect is stronger than the former, so it is in the principal's interest to adopt DS. For costly monitoring technology, the bonus of the supervisor have to provide incentives both for working and monitoring. So it will reinforce the first effect cited above. Which will dominate the second for high monitoring costs. In this case adopting MS will be preferable.

5 Conclusion

In this paper we shed some light on the possible interactions between formal contracts (those proposed by the principal) and informal relationship between agents. We show that there is substituability between these two ways of providing incentives. So their relative efficiency is determinant for the principal's choice. When the informativeness of the signals observable inside the team is sufficiently high, the principal will propose lower incentives and part of the coordination will be ensured by the agents' side contract. We show that an important element for structuring the optimal mix is the liability limit of the agents. For low values of M the principal uses the maximal mutual monitoring capacity of the team. When the liability limit is relaxed the principal uses stronger incentives and less mutual monitoring.

We also derive conditions for endogenous adoption of a costly mutual monitoring technology. We show that for higher M, the adoption of a mutual monitoring technology will be valuable only when its cost is sufficiently low.

Finally we briefly discuss the comparative efficiency of two organizational modes. We show that for low values of the monitoring cost, the principal always prefers to delegate the technology to one of the agents, rather than to both of them. However for high levels of the supervisory costs, the mutual monitoring structure dominates the unilateral supervision.

6 Appendix

6.1 Appendix A - proof of Lemma 1

The cost of the principal when agents are side contracting writes:

$$C = 2\big(p_{11}(\Delta w - (\overline{\alpha} - \underline{\alpha})t) + w_L\big) = 2\big(p_{11}(\frac{c - (\overline{\alpha} - \underline{\alpha})t}{p_{11} - p_{01}}) + t - M)\big)$$

The coordination agreement is profitable for the principal if: $(\overline{\alpha} - \underline{\alpha}) > \frac{p_{11} - p_{01}}{p_{11}}$. If this condition is verified it is immediate to see that the principal's cost is minimized for the largest possible $(\overline{\alpha} - \underline{\alpha})$.

Assume that there exist a type of side contract that maximizes the agents' joint utility function. Let us note it by $(\widetilde{\underline{\alpha}}; \widetilde{\overline{\alpha}}; \widetilde{t})$. The agents will be able to implement the high effort equilibrium with such a contract only if : $\widetilde{t} \leq t$, where t is the transfer authorized by the principal's grand contract. The agents' side contract will be incentive compatible only if $\frac{c - (p_{11} - p_{01})\Delta w}{\widetilde{\overline{\alpha}} - \widetilde{\underline{\alpha}}} \leq \frac{c - (p_{11} - p_{01})\Delta w}{\overline{\alpha} - \underline{\alpha}} \Leftrightarrow (\overline{\alpha} - \underline{\alpha}) < (\widetilde{\overline{\alpha}} - \widetilde{\underline{\alpha}})$. As we have seen the contract that maximizes the principals profit is the one with largest $\overline{\alpha} - \underline{\alpha}$. Thus the agents will be constrained to adopt the side contract that minimizes the principal's wage cost. At best $(\widetilde{\underline{\alpha}}; \widetilde{\overline{\alpha}}; \widetilde{t})$ will coincide with the one authorized by the principal.

6.2 Appendix B - proof of Lemma 2

The different punishment schemes we have to compare could be based on:

- Each agent's signal $(\underline{\alpha}(s_i); \overline{\alpha}(s_i))$.
- Both signal $(\underline{\alpha}(s_i; s_j); \overline{\alpha}(s_i; s_j))$.
- Each agent's signal and output $(\underline{\alpha}(s_i; y); \overline{\alpha}(s_i; y))$.
- Both signals and output $\underline{\alpha}(s_i; s_j; y); \overline{\alpha}(s_i; s_j; y))$.

Where s_i is the agent's signal, s_j is his team mate's signal, and y is the output realization. We note $\overline{\alpha}(\cdot) - \overline{\alpha}(\cdot) = \Delta\alpha(\cdot)$. Thus we have

$$\begin{aligned}
&\Delta\alpha(s_i) = (q - r) \\
&\Delta\alpha(s_i; s_j) = (q - r)(1 - r + \lambda r) \\
&\Delta\alpha(s_i; y) = (q - r - \lambda r(p_{11} - p_{01}) - p_{01}q + p_{11}r) \\
&\Delta\alpha(s_i; s_j; y) = ((q - r)(1 - r + \lambda r) - p_{01}q(1 - r + \lambda r) + p_{01}\lambda r + p_{11}r(1 - r)(1 - \lambda))
\end{aligned}$$

Thus we show that under the assumption of effort complementarity $\Delta\alpha(s_i; y) > \Delta\alpha(s_i; s_j; y)$, $\Delta\alpha(s_i) > \Delta\alpha(s_i; s_j)$, and $\Delta\alpha(s_i) > \Delta\alpha(s_i; y)$.

6.3 Appendix C - proof that the constraint guaranteeing that $(1; 1)$ maximizes the joint utility function is never binding for the principal.

In $t = 3$, for given terms of the grand contract $(\Delta w; w_L)$, the agents are choosing $(t; e_1; e_2)$ to maximize their joint utility.

The joint utility of the agents when they coordinate on $(0; 1)$, writes.

$$U(0; 1) + U(1; 0)$$

For the interval of incentive bonuses we are interested on, $(0; 0)$ is the unique non cooperative equilibrium. So one of the agents will work only if he receives the adequate incentives for doing so. Punishing him in case of bad signal realization is not sustainable. Thus we study the case when he receives a bonus from the other agent in case of "good" signal realization.

The following individual constraints must be satisfied:

$$\begin{cases} p_{01}\Delta w + w_L - c + (1-r)\lambda t > p_{00}\Delta w + w_L + (1-q)\lambda t & IC1 \\ p_{01}\Delta w + w_L - (1-r)t > p_{11}\Delta w + w_L - c - (1-r)t\lambda & IC2 \\ p_{01}\Delta w + w_L - c + (1-r)\lambda t > p_{00}\Delta w + w_L & IR1 \\ p_{01}\Delta w + w_L - (1-r)t > p_{00}\Delta w + w_L & IR2 \\ t + w_L \leq M \ LL \end{cases}$$

From IC1, we have $t \geq \dfrac{c - p_{01}\Delta w}{(q-r)\lambda}$.

The incentive compatible transfer implementing $(0;1)$ is higher than the one ensuring the agents' coordination on $(1;1)$ (under the assumption of effort complementarity). As far as the transfers the agents can commit on are constrained by the contract proposed by the principal, he will slacken the limited liability constraint just enough to implement the high effort equilibrium, which is not sufficient to implement $(0;1)$.

6.4 Appendix D - Proof of Propositions 1 and 2

When deciding to coordinate the agents are maximizing, their joint utility function under the following individual constraints:

$$\begin{cases} p_{11}\Delta w + w^L - c - t(r - \lambda r) \geq p_{00}\Delta w + w^L & CIR \\ p_{11}\Delta w + w^L - c - t(r - \lambda r) \geq p_{01}\Delta w + w^L - c - t(q - \lambda r) & CIC \\ t \leq M + w^L & LL \end{cases}$$

They fix the transfer at its minimal value:

$$t = \frac{c - (p_{11} - p_{01})\Delta w}{q - r}$$

Under the following constraints about the maximal value it could take:

$$\begin{cases} t \leq M + w^L & \Leftrightarrow \quad \Delta w \geq \dfrac{c - (q-r)(M + w^L)}{p_{11} - p_{01}} \\ t \leq \dfrac{p_{11}\Delta w - c}{r(1-\lambda)} & \Leftrightarrow \quad \Delta w \geq \dfrac{(q - \lambda r)}{p_{11}(q - \lambda r) - p_{01}(r - \lambda r)} \end{cases}$$

Let us solve the Principal's problem

$$\max_{\Delta w, w^L} -(p_{11}\Delta w + w^L) \tag{1}$$

under the constraints:

$$\begin{cases} \Delta w \geq \dfrac{c - (q-r)(M + w^L)}{p_{11} - p_{01}} & (1) \\ \Delta w \geq \dfrac{c(q - \lambda r)}{p_{11}(q - \lambda r) - p_{01}(r - \lambda r)} & (2) \\ w_L \geq -M & (3) \\ p_{11}\Delta w + w^L - c - (r - \lambda r)\dfrac{c - (p_{11} - p_{01})\Delta w}{(q - r)} \geq 0 & (4) \end{cases}$$

$$\Leftrightarrow$$

$$\begin{cases} \Delta w \dfrac{p_{11} - p_{01}}{q - r} - \dfrac{c}{q - r} + M + w^L \geq 0 & (\alpha) \\ \Delta w(p_{11}(q - \lambda r) - p_{01}(r - \lambda r)) - c(q - \lambda r) \geq 0 & (\beta) \\ w_L + M \geq 0 & (\gamma) \\ \Delta w \dfrac{p_{11}(q - \lambda r) - p_{01}(r - \lambda r)}{q - r} - c\dfrac{(q - \lambda r)}{q - r} + w^L \geq 0 & (\mu) \end{cases}$$

α, β, γ and μ are the corresponding multipliers.

The resolution of the programme will be done by:

$$
\begin{cases}
\dfrac{\partial L}{\partial w^L} = -1 + \alpha + \gamma + \mu = 0 & (5) \\
\dfrac{\partial L}{\partial \Delta w} = -p_{11} + \alpha \dfrac{p_{11} - p_{01}}{q - r} + \beta(p_{11}(q - \lambda r) - p_{01}(r - \lambda r)) + & \\
+\mu(\dfrac{p_{11}(q - \lambda r) - p_{01}(r - \lambda r)}{q - r}) = 0 & (6) \\
\alpha(\Delta w \dfrac{p_{11} - p_{01}}{q - r} - \dfrac{c}{q - r} + M + w^L) = 0 & (7) \\
\beta(\Delta w(p_{11}(q - \lambda r) - p_{01}(r - \lambda r)) - c(q - \lambda r)) = 0 & (8) \\
\gamma(w_L + M) = 0 & (9) \\
\mu(\Delta w \dfrac{p_{11}(q - \lambda r) - p_{01}(r - \lambda r)}{q - r} - c\dfrac{(q - \lambda r)}{q - r} + w^L) = 0 & (10)
\end{cases}
$$

$\alpha \neq 0$**,** $\beta = 0$**,** $\gamma = 0$**,** $\mu \neq 0$ **:** The corresponding multipliers' values are:

$$\alpha = \frac{(p_{11} - p_{01})(r - \lambda r)}{p_{11}(q - \lambda r) - p_{01}(r - \lambda r) - (p_{11} - p_{01})}$$

$$\mu = \frac{p_{11}(q - r) - (p_{11} - p_{01})}{p_{11}(q - \lambda r) - p_{01}(r - \lambda r) - (p_{11} - p_{01})}$$

α and μ, will be positive if and only if:

$$
\begin{cases}
q > r + \dfrac{p_{11} - p_{01}}{p_{11}} \\
et \\
q > \dfrac{(p_{11} - p_{01}) + p_{01}(r - \lambda r) + p_{11}\lambda r}{p_{11}}
\end{cases}
$$

It is easy to show that those two conditions, reduce to the single one: $q - r > \frac{p_{11} - p_{01}}{p_{11}}$, because $r + \frac{p_{11} - p_{01}}{p_{11}} > \frac{(p_{11} - p_{01}) + p_{01}(r - \lambda r) + p_{11}\lambda r}{p_{11}}$.

The binding constraints are (1) and (4), which give us the following values for Δw and w^L:

- $w^L = \dfrac{cp_{01} - M(p_{11}(q - \lambda r) - p_{01}(r - \lambda r))}{p_{11}(q - \lambda r) - p_{01}(r - \lambda r) - (p_{11} - p_{01})}$
- $\Delta w = \dfrac{M(q - r) - c(1 - (q - \lambda r))}{p_{11}(q - \lambda r) - p_{01}(r - \lambda r) - (p_{11} - p_{01})}$

We now replace these values for Δw and w^L, in the non binding constraints.

(2) will be verified if and only if: $M > \dfrac{cp_{01}}{p_{11}(q-\lambda r) - p_{01}(r-\lambda r)}$.

(3) will be verified if and only if: $M < \dfrac{cp_{01}}{p_{11}-p_{01}}$, which corresponds to the values for M, we are interested on.

We can show that $\Delta w > 0$. It is the case if: $M > \dfrac{c(1-(q-\lambda r))}{(q-r)}$. From the condition for (2) being verified we have $M > \dfrac{cp_{01}}{p_{11}(q-\lambda r) - p_{01}(r-\lambda r)}$. It is easy to see that as long as: $q - r > \dfrac{p_{11}-p_{01}}{p_{11}}$, the next inequality is always verified: $\dfrac{cp_{01}}{p_{11}(q-\lambda r) - p_{01}(r-\lambda r)} > \dfrac{c(1-(q-\lambda r))}{(q-r)}$.

It is trivial to show that $\dfrac{M(q-r) - c(1-(q-\lambda r))}{p_{11}(q-\lambda r) - p_{01}(r-\lambda r) - (p_{11}-p_{01})} < \dfrac{c}{p_{11}-p_{01}}$, for all the values for M such that $M < \frac{cp_{01}}{p_{11}-p_{01}}$.

$\alpha > 0$, $\beta = 0$, $\gamma > 0$, $\mu = 0$: The corresponding multipliers' values are: $\alpha = \dfrac{p_{11}(q-r)}{p_{11}-p_{01}}$ and $\gamma = \dfrac{(p_{11}-p_{01}) - p_{11}(q-r)}{p_{11}-p_{01}}$. γ will be positive if $q - r < \dfrac{p_{11}-p_{01}}{p_{11}}$.

The optimal contract in this case is:

- $w^L = -M$
- $\Delta w = \dfrac{c}{p_{11}-p_{01}}$

The two non binding constraints (2) and (4) are also verified for $M < \dfrac{cp_{01}}{p_{11}-p_{01}}$.

$\alpha > 0$, $\beta > 0$, $\gamma = 0$, $\mu = 0$: The corresponding multipliers' values are: $\alpha = 1$ et $\beta = \dfrac{p_{11}(q-r) - (p_{11}-p_{01})}{p_{11}(q-\lambda r) - p_{01}(r-\lambda r)}$. We have $\beta > 0 \Leftrightarrow q - r > \dfrac{p_{11}-p_{01}}{p_{11}}$.

The binding constraints are (1) and (2), and the terms of the resulting contract are as follows:

- $w^L = \dfrac{cp_{01}}{p_{11}(q-\lambda r) - p_{01}(r-\lambda r)} - M$
- $\Delta w = \dfrac{c(q-\lambda r)}{p_{11}(q-\lambda r) - p_{01}(r-\lambda r)}$

The constrainnt (3) is always verified because we have $\frac{cp_{01}}{p_{11}(q-\lambda r)-p_{01}(r-\lambda r)} > 0$.

The constraint (4) will be verified iff $M < \frac{cp_{01}}{p_{11}(q-\lambda r)-p_{01}(r-\lambda r)}$.

The following inequality $\frac{(p_{11}-p_{01})+p_{01}(r-\lambda r)+p_{11}\lambda r}{p_{11}} < \frac{c}{p_{11}-p_{01}}$, after simplifications gives us $p_{01}(q-r) > 0$, which is always true.

6.5 Appendix E - Proof of Proposition 3

The program of the principal writes:

$$\max_{\Delta w, w^L} -2(p_{11}\Delta w + w^L)$$

under the constraints:

$$\begin{cases} p_{11}\Delta w - c - a \geq 0 & \alpha \quad (14) \\ (p_{11}-p_{01})\Delta w - c + (M+w^L)\nu \geq 0 & \beta \quad (15) \\ M + w^L \geq 0 & \gamma \quad (16) \\ p_{11}\Delta w + w^L - c - a \geq 0 & \mu \quad (17) \end{cases}$$

It is equivalent to:

$$\begin{cases} \frac{\partial L}{\partial w^L} = -1 + \nu\beta + \gamma + \mu = 0 & (18) \\ \frac{\partial L}{\partial \Delta w} = -p_{11} + \alpha p_{11} + \beta(p_{11}-p_{01}) + \mu p_{11} = 0 & (19) \\ \alpha(p_{11}\Delta w - c - a) \geq 0 & (20) \\ \beta((p_{11}-p_{01})\Delta w - c + (M+w^L)\nu) \geq 0 & (21) \\ \gamma(w_L + M) \geq 0 & (22) \\ \mu(p_{11}\Delta w + w^L - c - a) \geq 0 & (23) \end{cases}$$

$\alpha > 0$, $\beta > 0$, $\gamma = 0$, $\mu = 0$: The corresponding multipliers' values are: $\beta = \frac{1}{\nu}$ and $\alpha = \frac{p_{11}\nu - (p_{11}-p_{01})}{p_{11}\nu}$. α will be positive if $\nu > \frac{p_{11}-p_{01}}{p_{11}}$.

Binding the constraints (14) and (15) gives us $\Delta w = \frac{c+a}{p_{11}}$ and $w^L = -M + \frac{cp_{01} - a(p_{11} - p_{01})}{p_{11}\nu}$.

The constraint (16) will be satisfied if: $a < \frac{p_{01}c}{p_{11} - p_{01}}$. These limit on the maximal value of the supervision cost guarantees that: $\frac{c+a}{p_{11}} > \frac{c}{p_{11} - p_{01}}$.

The constraint (17) will be satisfied if: $M < \frac{p_{01}c - (p_{11} - p_{01})a}{p_{11}\nu}$.

$\alpha = 0$, $\beta = 0$, $\gamma = 0$, $\mu > 0$: The multiplier value, satisfying both (18) and (19) is $\mu = 1$.

So (17) is binding, and we have: $p_{11}\Delta w + w^L = c + a$.

The following condition, guarantees that the principal's cost of implementing the high effort equilibrium will be lower in the case of mutual monitoring and side contracting between agents, than in the case of individually incentive remuneration scheme: $c + a < \frac{p_{11}c}{p_{11} - p_{01}} - M$. Which will be verified under the following condition on M: $M < \frac{cp_{01}}{p_{11} - p_{01}} - a$.

There are two possible cases:

1. For $\nu < \frac{p_{11} - p_{01}}{p_{11}}$. The three not binding constraints give us the following conditions:

$$\begin{cases} w^L < 0 \\ w^L < \dfrac{a(p_{11} - p_{01}) - cp_{01} + \nu p_{11} M}{(p_{11} - p_{01}) - \nu p_{11}} \\ w^L > -M \end{cases}$$

   The second and third condition will be satisfied simultaneously iff: $M > \frac{cp_{01}}{p_{11} - p_{01}} - a$, which is in contradiction with the condition derived above.

2. Soit $\nu > \frac{p_{11} - p_{01}}{p_{11}}$. The new system of conditions writes:

$$\begin{cases} w^L < 0 \\ w^L > \dfrac{cp_{01} - a(p_{11} - p_{01}) - \nu p_{11} M}{\nu p_{11} - (p_{11} - p_{01})} \\ w^L > -M \end{cases}$$

It is easy to show that these conditions will be satisfied simultaneously, for M such that: $\frac{p_{01}c-(p_{11}-p_{01})a}{p_{11}\nu} < M < \frac{cp_{01}}{p_{11}-p_{01}} - a$

6.6 Appendix F - Delegation to one of the agents

If the agent A_1 decides not to use the supervision technology, and if he wants the other agent to work, he must propose him a bonus with value: $\Delta t^{NS} = \frac{c}{p_{11}-p_{01}}$.

If A_1 use (and can commit on that) the supervision technology the incentive bonus proposed to A_2 will be: $\Delta t^{S} = \frac{c}{p_{11}-p_{01}(1-\nu)}$.

To simplify the analysis we assume $M \equiv 0$.

The principal's program writes:

$$\max_{\Delta w, w^L} -2(p_{11}\Delta w + w^L)$$

under the constraints:

$$\begin{cases} p_{11}(\Delta w - \Delta t^S) - c - a \geq p_{11}(\Delta w - \Delta t^{NS}) - c & (24) \\ p_{11}(\Delta w - \Delta t^S) - c - a \geq p_{01}(\Delta w - \Delta t^S) - a & (25) \\ p_{11}(\Delta w - \Delta t^S) - c - a \geq p_{01}(\Delta w - \Delta t^{NS}) & (26) \\ p_{11}(\Delta w - \Delta t^S) - c - a \geq p_{01}\Delta w - c & (27) \\ p_{11}(\Delta w - \Delta t^S) + w^L - c - a \geq 0 & (28) \end{cases}$$

The first constraint is the IC for the supervision effort. The second the IC for the productive effort. The third one is the incentive constraint for both efforts. (27) guarantees that the agent A_1, will prefer to share the total bonus with his colleague, making him work, to the case of being the sole working agent and keep Δw. And finally we have the participation constraint.

The first constraint gives us the maximal value for the supervision cost $\bar{a} = \frac{cp_{11}p_{01}\nu}{(p_{11}-p_{01})(p_{11}-p_{11}+p_{11}\nu)}$. For supervision costs above this value, there is no interest for A_1 to supervise his team mate.

The sign of the next expression $p_{01}(\Delta t^{NS} - \Delta t^{S}) - a \equiv B$, determines which of the constraints (25) or (26) will be binding, which will fix the Δw value.

If $B > 0$ the binding constraint is (25), and conversely for $B < 0$, (26) will be binding.

The last constraint is always slack, under the assumption of effort complementarity.

6.7 Appendix G - Costs comparison

The case of $a < \frac{c{p_{01}}^2\nu}{(p_{11}-p_{01})(p_{11}-(1-\nu)p_{01})}$

The difference between incentive costs in the case of delegation, and in those of mutual supervision writes:

$$G(a) = \frac{p_{11}c}{p_{11} - p_{01}} + \frac{p_{11}c}{p_{11} - (1-\nu)p_{01}} - 2(c + a) - \frac{c(p_{01}c - (p_{11} - p_{01})a}{p_{11}\nu}$$

$$\frac{\partial G(a)}{\partial a} = -2 + \frac{2}{\nu} - \frac{2p_{01}}{p_{11}\nu}$$

This expression is always negative for $\nu > \frac{p_{11}-p_{01}}{p_{11}}$. So we explain a such that $G(\bar{a}) = 0$. As $G(a)$ is a decreasing function on a for the values of $\nu > \frac{p_{11} - p_{01}}{p_{11}}$, so we will have $G(a) > 0$, if $a < \bar{a}$.

$$G(\bar{a}) = 0$$

$$a = -\frac{c\nu p_{11}(2 + \frac{2p_{01}}{\nu p_{11}} - p_{11}(\frac{1}{p_{11}-p_{01}} + \frac{1}{p_{11}-(1-\nu)p_{01}})}{2(p_{01} - (1-\nu)p_{11})}$$

This expression is increasing in ν and negative for it's highest value: $\nu = 1$. Then $\bar{a} < 0$, $\forall \nu \in [\frac{p_{11}-p_{01}}{p_{11}}; 1]$. We can conclude that for low values of the supervisory cost the principal will prefer to delegate the supervision and the contracting relation to one of the agents, rather than to both of them.

The case of $a > \dfrac{c{p_{01}}^2\nu}{(p_{11}-p_{01})(p_{11}-(1-\nu)p_{01})}$

$G(a) = \frac{p_{11}(c+a)}{p_{11}-p_{01}} + \frac{p_{11}c}{p_{11}-(1-\nu)p_{01}} - \frac{cp_{11}{p_{01}}^2}{(p_{11}-p_{01})^2(p_{11}-(1-\nu)p_{01}} - 2(c+a) - \frac{c(p_{01}c-(p_{11}-p_{01})a}{p_{11}\nu}$
From $G(\bar{a}) = 0$, we can show that if $\nu \in [\dfrac{p_{11}-p_{01}}{p_{11}}; 1]$, then $\bar{a} < \dfrac{cp_{01}p_{11}\nu}{(p_{11}-p_{01})(p_{11}-(1-\nu)p_{01})}$

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