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ON THE ROLE OF COMMITMENT IN A CLASS OF SIGNALLING PROBLEMS

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Abstract

We consider a class of signalling problems in which the informed player, after sending a message, performs some further action simultaneously with the uninformed player's response. Two extensive-form games of this signalling problem are considered. First, the informed player can commit to his subsequent action at the time of signalling. Second, the informed player's announcement for his action is not binding at the time of performance. We show that commitment ability by the informed player with respect to his subsequent action leads to greater communication: In the case of commitment, the informed player may completely reveal his private information, whereas if commitment is not possible, no private information can be signalled by the informed player.

As an example, we focus on a principal-agent relationship in which the principal can monitor the agent's action at a fixed cost. Monitoring cost is private information of the principal. Based on this information, he offers a compensation scheme and announces a monitoring policy. Monitoring is assumed to take place simultaneously with the agent's choice of an action.

Keywords: Commitment, Signalling Game, Principal-Agent Relationship

JEL Classification: C72, D82

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1. INTRODUCTION

In this paper we examine the qualitative impact of commitment on the amount of information transmitted in equilibrium. The problem is studied in a class of signalling problems in which the informed player, after sending a message, performs some further action simultaneously with the uninformed player's response. We show that commitment ability by the informed player with respect to his subsequent action may lead to greater communication. In particular, we show that under certain assumptions, the informed player may completely reveal his private information if commitment is possible, whereas if commitment to his subsequent action is impossible, no information is transmitted in equilibrium. The basic intution behind this result is that the lack of commitment for the informed player is accompanied with an incentive compatibility constraint that excludes signalling his private information in equilibrium.

As an example, we study a principal-agent relationship in which the principal can monitor the agent's choice of an action at a fixed cost. Here, the principal is the informed player and the agent is the uninformed player. Before contracting starts, the principal learns his monitoring cost. This cost determines his type. Based on this information, the principal offers a compensation scheme which specifies the payment to the agent and the principal's monitoring policy. After agreeing to contracting, the agent takes an action which is not directly observable for the principal. Simultaneously with the agent's choice of an action, the principal can monitor the agent's behavior. Monitoring is assumed to be observable and verifiable. The outcome, as the result of the agent's action, is assumed to be observable but not verifiable. Hence, the compensation scheme fixes the payment to the agent conditional on the principal's monitoring choice and the agent's action.

Suppose that the principal can commit to his monitoring decision at the time of contracting. Since the principal is obliged to perform his monitoring as announced, the agent can base his choice of an action on the compensation scheme and the principal's monitoring announcement. The standard theory of signalling games (see e.g. Banks/Sobel [1987], Cho/Kreps [1987]) would suggest that in equilibrium principals with different monitoring cost would signal their private information by means of different compensation schemes and monitoring policies. In fact, after the agent agreed to contracting, monitoring cost has no further influence on his expected utility and, hence, do not influence his behavior when deciding on his action. As a consequence, the principal's choice of a compensation scheme and a monitoring policy is based only on his own monitoring cost. Therefore, the principal signals his monitoring cost. His private information is completely revealed in equilibrium.

Is this conclusion changed, if we assume that the announced monitoring device is not binding ex-post? Suppose, for example, that the principal's compensation scheme induces the agent to choose the desired action. Since monitoring is costly, the principal can save on monitoring cost by not monitoring. This, of course, will be foreseen by the agent. So, in general, the principal's monitoring announcement is not credible at the time of performance. In this situation, sequential rationality requires the principal to arrange his compensation scheme such that monitoring is still a credible threat. In particular, monitoring is credible only if the principal is indifferent regarding to this decision [1]. As a result, the agent receives a premium of the amount of the principal's monitoring cost in case of no monitoring, in addition to his payment if the principal monitors [2].

To discuss the credibility problem within the framework of the signalling problem, note that if the principal cannot commit to his monitoring policy at the time of contracting, only the compensation scheme can serve to signal his monitoring cost. A credible announcement of his monitoring activities is not possible.

The consequences of the lack of commitment are best demonstrated in the case in which there are just two cost types, c_1 and c_2, with $c_1 < c_2$. Suppose that a principal with cost c_i would signal his private information and offer a compensation scheme C_i, $i = 1, 2.$ with $C_1 \neq C_2$. Then both types of principal have an incentive to exploit their information advantage at the time of monitoring. To see this, consider a principal with high cost c_2 who offers the compensation scheme C_1. Because the principal with cost c_1 pays the agent a premium c_1 in the case of no monitoring, the principal with cost c_2 would never monitor the agent, for the premium c_1 is lower than his monitoring cost c_2. As a result, a principal with high cost prefers to offer C_1 instead of C_2. Similarly, if a principal with low cost c_1 offers the compensation scheme C_2, he would monitor with certainty, for his monitoring cost is lower than the additional payment c_2 in the case of no monitoring. Hence, he can increase his profit by offering C_2 instead of C_1. Thus, each type of principal would have an incentive to imitate the other. Of course, at least in equilibrium, the agent will anticipate this behavior by a principal. In fact, the analysis shows that the lack of commitment implies that a principal with privately known monitoring cost cannot signal his information in equilibrium. Hence, principals with different monitoring costs will offer an identical compensation scheme.

In the game theoretic literature on auditing and tax evasion, the value of commitment by the auditor with respect to his auditing policy is analysed by Reinganum/Wilde [1985], [1986]. However, these authors do not study private information by the auditor. The role of private information of the principal prior to contracting with the agent is studied in Myerson [1983] and Maskin/Tirole [1990], [1992] [3]. The lack of commitment, however, is not considered in this literature. Imperfect commitment by the principal is emphasized in the articles by Laffont and Tirole [1988] and Fudenberg and Tirole [1990] [4]; these authors do not focus on asymmetric information at the time of contracting.

The paper is organized as follows. In Section 2, we describe the basic principal-agent model in which the principal has the possibility to monitor the agent's choice of an action at some fixed cost. In this section, the principal's monitoring cost are assumed to be common knowledge. Section 3 introduces the aspect of private information by the principal with respect to his monitoring cost. In Section 4 we extend the basic principal-agent model in several directions. Section 5 generalizes our results to a class of signalling problems.

2. MONITORING IN A PRINCIPAL-AGENT RELATIONSHIP

In order to concentrate on the essential features of the commitment problem, we study a very simple model of a principal-agent relationship. A principal offers a compensation scheme to an agent for a joint venture. Under this arrangement, the agent is to take an action $a^* \in \mathcal{A}$. For simplicity, we assume that the agent's action set is $\mathcal{A} = \{a_L, a_H\}$. That is, the agent can either decide to work hard and choose the action a_H, or he decides to be lazy and chooses the action a_L (see Section 4 for the case of a continuum of actions). His action a determines an outcome $\mathcal{B}(a)$ which we will take to be the principal's gross profit. $\mathcal{B}(a)$ is assumed to be observable but not verifiable (see e.g. Hart/Moore [1988]). Hence, the agent's payment cannot depend on the outcome. The agent's action is not directly observable by the principal. However, the principal can monitor the agent's decision at a cost $c > 0$. Monitoring reveals the agent's action completely.

The compensation scheme fixes the agent's payment conditional on the principal's monitoring choice and the action taken by the agent. If no monitoring takes place, the agent's payment cannot depend on his action. Hence, one can think of a compensation scheme as a function C:

$$\begin{aligned} C: \mathcal{A} \times \{mo, nomo\} &\rightarrow [\underline{I}, \infty) \quad \text{such that} \\ C(a, mo) &= I(a) \quad \text{for } a \in \mathcal{A}, \\ C(a, nomo) &= J \quad \text{independent of } a \in \mathcal{A}. \end{aligned}$$

$C(a, mo)$ is interpreted as the agent's payment, if the principal monitors his decision; $C(a, nomo)$ denotes the agent's payment in a situation in which no monitoring takes place.

The principal is assumed to be risk neutral. He is interested in net profit, that is, he maximizes gross profit minus the payment to the agent minus his cost for monitoring.

The agent has a von Neumann-Morgenstern utility function $\mathcal{U}(a, I)$ which depends on the action a he chooses and the payment I. For simplicity, we assume $\mathcal{U}(a, I) = \mathcal{V}(I) - \mathcal{K}(a)$, where $\mathcal{V}(I)$ denotes the agent's utility from income I and $\mathcal{K}(a)$ denotes his disutility from taking action a. Formally, we assume that $\mathcal{V}(\cdot)$ is a real-valued, concave, continuous and strictly increasing function defined on $[\underline{I}, \infty)$ and $\mathcal{K}(\cdot)$ is a real-valued function, $\mathcal{K}(a_L) < \mathcal{K}(a_H)$.

Let $\bar{\mathcal{U}}$ denote the agent's reservation utility, i.e., his expected level of utility he can achieve by working elsewhere. To ensure that the principal can lower the agent's expected utility to his reservation utility, we assume that $\mathcal{U}(a_L, \underline{I}) < \bar{\mathcal{U}}$. Moreover, we assume that $\mathcal{U}(a_L, \underline{I}) > -\infty$. Thus, the agent cannot be penalized by an infinitely large fine.

Consider the principal's problem if he wishes to implement an action $a \in \mathcal{A}$. He then has to find a compensation scheme and a monitoring policy which minimizes the expected cost of getting the agent to choose this action. Note that if the principal wishes to implement the action a_L, he should pay the agent a constant payment without monitoring the agent's behavior. This yields optimal risk sharing, as the agent is risk averse and the principal is risk neutral. Therefore, the principal's problem is of interest only if he wishes to implement the action a_H. Consequently, we assume in the following that the principal's profit is higher, if the agent chooses a_H instead of a_L.

2.1 The case of commitment:

Assume that the principal can commit to his monitoring decision at the time of contracting. Let $p \in [0,1]$ denote his monitoring probability. If he monitors the agent, he will penalize him for any deviation from a_H. Since the agent's incentives to choose a_H are the larger the larger the penalty for a deviation, it is optimal for the principal to punish the agent as much as possible for any non-complying behavior. Using the principle of maximum deterrence of Baron/Besanko [1984], we assume, without loss of generality, that $I(a_L) = \underline{I}$. Then the principal's problem of minimizing his expected cost to implement action a_H leads to the following minimization program (P) (with $I = I(a_H)$): [5]

$$\text{Choose } (I, J, p) \text{ to minimize } \left[p(I+c) + (1-p)J\right] \text{ subject to}$$
$$p\mathcal{V}(I) + (1-p)\mathcal{V}(J) - \mathcal{K}(a_H) \geq \bar{\mathcal{U}} \qquad (IRC)$$
$$p\mathcal{V}(I) + (1-p)\mathcal{V}(J) - \mathcal{K}(a_H) \geq p\mathcal{V}(\underline{I}) + (1-p)\mathcal{V}(J) - \mathcal{K}(a_L) \qquad (ICA)$$

The first constraint (IRC) guarantees the acceptance by the agent, the second constraint (ICA) ensures that he actually chooses the action desired by the principal.

Proposition 2.1:

For every $c > 0$ let $(I^*(c), J^*(c), p^*(c))$ be the solution of the principal's minimization program (P). Then

$$I^*(c) > J^*(c) \quad \text{and} \quad p^*(c) \in (0,1).$$

Moreover, the following properties hold:

$$\frac{\partial}{\partial c} I^*(c) > 0, \quad \frac{\partial}{\partial c} J^*(c) < 0, \quad \frac{\partial}{\partial c} p^*(c) < 0.$$

Proof: *see Appendix A*

If the principal does not monitor the agent's behavior, he is completely uninformed about the action the agent has taken. Hence, the amount of payment to the agent in case of no monitoring contributes positively to the agent's utility, independent of the action he chooses. Hence, a high payment in this case would increase his incentives not to perform the action a_H. On the other hand, if the principal rewards the agent for taking the desired action in case of monitoring, the agent's incentives to comply with the principal's interests are high. Hence, as the first part of the proposition shows, the agent receives a higher payment, if monitored by the principal, as compared to his payment, if not monitored.

Moreover, the first part of the proposition states that it is always optimal for the principal not to monitor the agent's choice of an action with certainty. To see this, suppose that this claim is false. Then the principal minimizes his implementation cost, if he pays the agent a payment $\bar{I}$ which is determined by the agent's reservation utility, i.e. $\mathcal{V}(\bar{I}) = \bar{\mathcal{U}} + \mathcal{K}(a_H)$. Note, that the incentive constraint (ICA) is not binding in this case. Hence, by paying the agent $\bar{I}$ in case of no monitoring, the principal can reduce his implementation cost. In fact, he can save $\bar{p}c$ as long as he chooses his monitoring probability $\bar{p}$ such that the incentive constraint (ICA) is not violated.

The second part of the proposition follows immediately from the fact that if monitoring cost c increases, monitoring becomes more costly for the principal. To save on cost, he reduces his monitoring probability which in turn implies a higher payment to the agent in case of monitoring.

2.2 The case of non-commitment:

Consider now a principal-agent relationship in which the principal's monitoring announcement at the time of contracting is not binding ex-post. In this situation, the principal faces the following problem: Suppose that the compensation scheme (I^*, J^*) and the announced monitoring policy p^* (the solution in the case of commitment, Proposition 2.1) induces the agent to act in his interests. Since monitoring is costly, the principal can save on cost by not monitoring the agent. This, of course, will be foreseen by the agent so the announced monitoring policy will be not credible. Therefore, the principal has to rearrange the compensation scheme such that his threat to monitor becomes credible ex-post. To capture this problem, we require sequential rationality of the monitoring policy as well as of the agent's behavior:

(1) Regardless of which compensation scheme has been offered by the principal and signed by the agent, the principal's monitoring decision and the agent's choice of an action are such that (1.1) the principal chooses his monitoring to minimize his implementation cost, given the agent's action and (1.2) the agent chooses his action to maximize his expected utility given the monitoring decision by the principal.

(2) The agent accepts any compensation scheme if his expected utility exceeds his reservation utility, given that he foresees the principal's behavior according to (1).

(3) The principal offers the compensation scheme which maximizes his expected profit, given that he foresees the agent's behavior according to (1) and (2).

Note, that the principal's problem, as stated in (3) differs from the problem (P) in the case of commitment only with respect to the requirement (1). That is, the lack of commitment by the principal with repect to his monitoring announcement is accompanied with an additional incentive constraint. To incorporate this sequential rationality constraint into his minimization program, suppose that the principal offers an incentive device (I, J) and that the agent complies with his interests. The principal's expected implementation cost is then given by [6]

$$p(I+c)+(1-p)J.$$

Sequential rationality with respect to his choice of a monitoring probability $p \in [0,1]$ requires that the principal trades off the payment J in case of no monitoring and the sum of the payment I and his monitoring cost c in the case of monitoring:

$$p = \begin{cases} 0 & \text{if } J-I<c \\ 1 & \text{if } J-I>c \\ \in [0,1] & \text{if } J-I=c \end{cases} \qquad (ICP)$$

Without loss of generality, set $J = I + c$. Then the incentive constraint (ICP) holds trivially and the principal's problem of minimizing his expected cost to implement an action a_H leads to the following program $(\hat{P})$:

$$\text{Choose } (I,p) \text{ to minimize } I \text{ subject to}$$

$$p\mathcal{V}(I)+(1-p)\mathcal{V}(I+c)-\mathcal{K}(a_H) \geq \bar{\mathcal{U}} \qquad (IRC)$$

$$p\mathcal{V}(I)+(1-p)\mathcal{V}(I+c)-\mathcal{K}(a_H) \geq$$
$$p\mathcal{V}(\underline{I})+(1-p)\mathcal{V}(I+c)-\mathcal{K}(a_L) \qquad (ICA)$$

Proposition 2.2:

For every $c > 0$ let $(I^{**}(c), J^{**}(c), p^{**}(c))$ denote a solution of the principal's minimization program $(\hat{P})$. Then

$$I^{**}(c)+c = J^{**}(c) \quad \text{and} \quad p^{**}(c) \in (0,1).$$

Moreover, the following properties hold:

$$\frac{\partial}{\partial c}I^{**}(c) < 0, \quad \frac{\partial}{\partial c}J^{**}(c) > 0, \quad \frac{\partial}{\partial c}p^{**}(c) > 0.$$

Proof: *see Jost [1991]*

Due to the lack of commitment, the principal's monitoring decision is restricted by sequential rationality. This implies that monitoring is credible only if the principal is indifferent with respect to this decision. As a consequence, the principal pays the agent a premium equal to his monitoring cost in the case of no monitoring. An argument similar to the one for Proposition 2.1 shows that it is optimal for the principal to monitor the agent's behavior with positive probability less than one.

The results of the second part of the proposition differ from our findings in a situation in which the principal can commit to his monitoring policy at the time of contracting, see Proposition 2.1. To see this, note that in the case of commitment monitoring has two effects: It serves as a device for preventing non-compliance (a disciplinary effect) and it rewards the agent for complying with the principal's interests (a positive income effect). Consider now the situation in which the principal's monitoring announcement is not binding ex-post. Sequential rationality implies that the principal pays the agent less payment, if he monitors his action as compared to the agent's payment if he does not monitor. Hence, the agent prefers not to get monitored, regardless of the action he chooses. Thus, monitoring can serve as an incentive device but not as a mechanism which rewards the agent for complying with the prescribed action. This has the following implications on the principal's strategic variables, if monitoring cost goes up. Suppose that the principal would reduce his monitoring probability by Δp. Then the agent's expected utility increases by $\Delta p[\mathcal{V}(I+c)-\mathcal{V}(I)]$, if he chooses action a_H. On the other hand, reducing the monitoring probability by Δp increases the agent's expected utility by $\Delta p[\mathcal{V}(I+c)-\mathcal{V}(\underline{I})]$, if he deviates from the desired action. Note that the second change in utility is greater than the first one. To guarantee the incentive constraint (ICA), the principal has to pay the agent a higher payment $I+\Delta I$. However, reducing the monitoring probability and increasing the agent's payment if he gets monitored implies that the agent can expect a higher utility than his reservation utility, if he chooses the desired action. That is, the individual rationality constraint (IRC) is not binding. But this contradicts the fact that the principal can always reduce the agent's payment such that the agent can expect his reservation utility $\bar{\mathcal{U}}$. As a consequence, if monitoring cost increases, the principal's monitoring probability increases which in turn implies that the agent's payment in case of monitoring decreases, but increases in case of no monitoring.

3. A PRIVATELY INFORMED PRINCIPAL AND THE ROLE OF COMMITMENT

We now extend the basic model of Section 2 and assume that the principal has private information regarding his monitoring cost. The cost c can take one of two values c_1 or c_2, where $0 < c_1 < c_2$. We identify the principal's type with his monitoring cost c_i, $i = 1, 2$, and assume that the type is drawn according to some probability distribution over $\{c_1, c_2\}$ that is common knowledge. We denote with $\delta \in [0,1]$ the probability that the principal is of type c_1.

We analyze two possible extensive forms of the underlying principal-agent relationship. First, we study a model in which the principal can commit to his monitoring decision at the time of contracting. That is, the principal's announced monitoring probability is binding ex-post. Second, we consider a situation in which the principal cannot commit ex-ante to his monitoring decision and must decide on his monitoring simultaneously with the agent's choice of an action.

3.1 The case of commitment:

Suppose that before contracting starts the principal learns that his monitoring cost is $c_i, i = 1,2$. Let C_i be the compensation scheme he offers and let p_i be the monitoring probability he announces. We assume that the principal can commit to his monitoring decision at this stage of the relationship. In terms of a signalling game, this model refers to the case in which the message send by the principal consists of a compensation scheme and a monitoring policy.

Let $\delta_i(C,p)$ denote the agent's posterior belief that the principal who offers the contract $C = (I,J)$ and announces the monitoring policy p has monitoring cost c_i. At least in equilibrium, the agent uses Bayes' rule to compute his posterior beliefs. Then $(C_1^*, p_1^*, C_2^*, p_2^*)$ is a perfect Bayesian equilibrium of the principal-agent game, if $(C_1^*, p_1^*, C_2^*, p_2^*)$ is the solution of the following 2 independent maximization programs:

Choose $(I_1, J_1, p_1, I_2, J_2, p_2)$ such that for $i = 1,2$:

(I_i, J_i, p_i) maximizes $\quad \mathcal{B}(a_H) - [p(I + c_i) + (1-p)J]$ subject to

$$\sum_{j=1}^{2} \delta_j^*(C,p)\,[p\mathcal{V}(I) + (1-p)\mathcal{V}(J)] - \mathcal{K}(a_H) \geq \bar{U}$$

$$\sum_{j=1}^{2} \delta_j^*(C,p)\,[p\mathcal{V}(I) + (1-p)\mathcal{V}(J)] - \mathcal{K}(a_H) \geq \sum_{j=1}^{2} \delta_j^*(C,p)\,[p\mathcal{V}(\underline{I}) + (1-p)\mathcal{V}(J)] - \mathcal{K}(a_L)$$

and beliefs δ_j^* are consistent with Bayes' rule.

Suppose that a compensation scheme C_i is offered and a monitoring policy p_i is announced by the principal. Then the pair (C_i, p_i) determines uniquely the agent's expected utility for every decision $a \in \mathcal{A}$. In particular, the agent's expected utility is independent of the actual type of the principal. That is, if the principal has announced (C_i, p_i), his monitoring cost has no further influence on the agent's expected utility and, hence, do not influence the agent's behavior in this situation:

$$\sum_{j=1}^{2} \delta_j^*(C_i,p_i)\,[p_i\mathcal{V}(I_i) + (1-p_i)\mathcal{V}(J_i)] - \mathcal{K}(a_H) = [p_i\mathcal{V}(I_i) + (1-p_i)\mathcal{V}(J_i)] - \mathcal{K}(a_H)$$

In consequence, each type of principal decides on his decisions (C_i, p_i) independent of the monitoring cost of the other type. His minimization problem when implementing the action a_H is therefore identical to the program (P) in Section 2. This implies that in equilibrium the choice (C_i^*, p_i^*) depends only on the principal's actual monitoring cost c_i. He maximizes his expected net profit as in a relationship without adverse selection issues.

From Proposition 2.1 it then follows that any equilibrium in the case with commitment is a separating one. According to Proposition 2.1, the pair (C_i^*, p_i^*) is determined by the principal's monitoring cost. Because the principal can precommit to his monitoring decision, the agent chooses his action independent of his belief about the actual type of principal. Thus, a principal with high monitoring cost cannot gain by imitating a principal with low cost, and vice versa.

Proposition 3.1:

The only equilibrium in the principal-agent relationship with commitment by the principal to his monitoring policy is a separating one. Let (C_1^*, p_1^*) and (C_2^*, p_2^*) be the equilibrium strategies of a principal with low and high monitoring cost, respectively. Then the following properties hold:

$$I_1^* < I_2^*, \quad J_1^* > J_2^*, \quad p_1^* < p_2^*.$$

In equilibrium a principal with lower monitoring cost announces to monitor with a higher probability than a principal with higher cost would do. He pays the agent more in the case he does not monitor but less if he monitors, compared to a principal with higher monitoring cost.

3.2 The case of non-commitment:

Suppose that a principal with private information about his monitoring cost cannot commit to his monitoring policy at the time, he offers a compensation scheme. Instead, he is to decide on his monitoring simultaneously with the agent's choice of an action. Then his monitoring decision cannot serve as a message to signal his monitoring cost.

We analyze this game using the concept of sequential equilibrium. In a sequential equilibrium, the following properties hold:

(1) Regardless of which compensation scheme C has been offered by the principal and signed by the agent, the principal decides on his monitoring to minimize his implementation cost, given the agent's choice of an action (1.1) and the agent selects an action that maximizes his expected utility, given his posterior assessment about the principal's type and the principal's monitoring decision (1.2). We denote with $\delta(C)$ the agent's posterior belief that the principal has monitoring cost c_1. At least in equilibrium, the agent uses Bayes' rule to calculate this belief.

(2) On the basis of his posterior belief $\delta(C)$, the agent signs any arrangement C if his expected utility exceeds his reservation utility, given that he foresees the principal's monitoring choice according to (1).

(3) The principal offers a compensation scheme C^* that maximizes his expected net profit as the sum of his gross profit minus the implementation cost, given that he foresees the agent's behavior according to (1) and (2).

The lack of commitment to his monitoring desicion has important consequences on the behavior of a principal in equilibrium.

Proposition 3.2:

The only equilibrium in the principal-agent relationship without commitment by the principal to his monitoring policy is a pooling equilibrium of the following form. There exist values $0 < \bar{\nu}_1 < \bar{\delta}_1 < \bar{\delta}_2 < \bar{\nu}_2 < 1$ *such that*

i) if $\delta \leq \bar{\delta}_1$ *then*

$$J^* = I^* + c_2,\ p_1^* = 1,\ p_2^* = \frac{1}{1-\delta} \cdot (\bar{\delta}_2 - \delta),$$

$$\delta(C^*) = \delta,\ \delta(C) \leq \bar{\nu}_1 \quad \text{for all } C \neq C^*,$$

ii) if $\delta \geq \bar{\delta}_2$ *then*

$$J^* = I^* + c_1,\ p_1^* = \frac{\bar{\delta}_1}{\delta},\ p_2^* = 0,$$

$$\delta(C^*) = \delta,\ \delta(C) \geq \bar{\nu}_2 \quad \text{for all } C \neq C^*,$$

iii) if $\delta \in (\bar{\delta}_1, \bar{\delta}_2)$ *then*

the equilibrium in i) can be supported with beliefs

$$\delta(C^*) = \delta,\ \delta(C) \leq \bar{\nu}_1 \quad \text{for } C \neq C^*,$$

the equilibrium in ii) can be supported with beliefs

$$\delta(C^*) = \delta,\ \delta(C) \geq \bar{\nu}_2 \quad \text{for } C \neq C^*.$$

The intuition behind this result is as follows. Suppose that the claim of Proposition 3.2 is false and there exists an equilibrium in which a principal with cost c_i offers a compensation scheme C_i, $i = 1, 2$, with $C_1 \neq C_2$. Then, after the arrangement is accepted by the agent, the principal still must decide on his monitoring behavior. The assumption that the principal cannot commit to his monitoring at the time contracting puts him in the position to exploit his information advantage. In fact, suppose that a principal with low monitoring cost c_1 offers the scheme C_2 of the other type. In equilibrium, the agent believes that he is contracting with a principal having cost c_2 and chooses an action, taking into account possible monitoring by the principal of type c_2 (note that under C_2 monitoring is credible ex-post only if the agent receives a premium c_2 when no monitoring takes place). But then the principal with cost c_1 prefers to monitor the agent with certainty, for his monitoring cost is lower than the premium c_2 he has to pay in case of no monitoring. From Proposition 2.2 it then follows that the principal with cost c_1 can increase profit by offering C_2 instead of C_1. Similarly, a principal with high cost c_2 who offers the scheme C_1 can make use of his private information in the following way: He prefers not to monitor the agent, for his cost c_2 is higher than the premium c_1. Again, according to Proposition 2.2, the arrangement C_1 yields higher profit than C_2. Of course, in equilibrium this behavior will be foreseen by the agent and excludes the existence of separating compensation schemes. In fact, Proposition 3.2 states that the only equilibrium in the principal-agent relationship without commitment is a pooling one in which principals with different monitoring costs offer an identical compensation scheme. Of course, different types of principal will differ in their monitoring policies.

We discuss Proposition 3.2 using the following path of argumentation. First, we show that there cannot exist a separating equilibrium. Second, we analyze the structure of the pooling equilibrium. Third, we argue that there cannot exist a hybrid equilibrium, i.e., an equilibrium in which at least one type of principal randomizes between offering a pooling or a separating compensation scheme.

Separating equilibria

Suppose that, as in the case of commitment, a principal with private information about his monitoring cost signals his information by means of his compensation scheme. Let C_i be the compensation scheme offered by a principal with monitoring cost c_i, $i = 1, 2$. According to Proposition 2.2., sequential rationality requires the principal to transfer his monitoring cost to the agent if he does not monitor.

First, consider the situation of a principal with low monitoring cost c_1. If he offers the compensation scheme C_1, his implementation cost in equilibrium is $C_1(a_H, mo)+c_1$. Suppose that he deviates to the arrangement C_2. Since the principal with cost c_2 is indifferent in equilibrium between monitoring or not, a principal with lower monitoring cost prefers to monitor with certainty, for his monitoring cost c_1 does not exceed the premium c_2 of the scheme C_2 in case of no monitoring: $C_2(a_H, mo) + c_1 < C_2(a_H, nomo) = C_2(a_H, mo) + c_2$. Hence, if a principal with cost c_1 would deviate to C_2, his implementation cost is $C_2(a_H, mo) + c_1$.

Alternatively, consider a principal with high monitoring cost c_2. If he offers the compensation scheme C_2 in equilibrium, his implementation cost is $C_2(a_H, mo) + c_2$. Suppose that he would offer the arrangement C_1. Because the principal with low monitoring cost c_1 is indifferent in equilibrium between monitoring or not, the principal with cost c_2 has no incentive to monitor the agent's behavior at all. He gains by not paying an amount c_2 for monitoring, but only a premium c_1 as an additional payment to the agent in case of no monitoring: $C_1(a_H, mo) + c_1 = C_1(a_H, nomo) < C_1(a_H, mo) + c_2$. Hence, if a principal with monitoring cost c_2 offers C_1, his implementation cost is $C_1(a_H, mo) + c_1$.

We assumed that (C_1, C_2) are separating equilibrium compensation schemes. As a consequence, a principal of type c_i has no incentives to deviate from his equilibrium arrangement. In particular, a principal cannot gain by offering the equilibrium arrangement of the other type. That is, the principal's expected net profit in equilibrium exceeds his expected profit, if he offers the equilibrium scheme of the other type. Hence, for a principal with cost c_1 equilibrium requires

$$\begin{aligned} B(a_H) - \left[C_1(a_H, mo) + c_1\right] &\geq B(a_H) - \left[C_2(a_H, mo) + c_1\right], \\ \text{i.e.,}\quad C_2(a_H, mo) &\geq C_1(a_H, mo). \end{aligned} \tag{1}$$

Moreover, a principal with cost c_2 cannot gain in equilibrium by offering the compensation scheme C_1. Hence

$$\begin{aligned} B(a_H) - \left[C_2(a_H, mo) + c_2\right] &\geq B(a_H) - \left[C_1(a_H, mo) + c_1\right], \\ \text{i.e.,}\quad C_1(a_H, mo) &\geq C_2(a_H, mo) + (c_2 - c_1). \end{aligned} \tag{2}$$

Summarizing the restrictions (1) and (2) yields $c_2 - c_1 \leq 0$, a contradiction.

Pooling equilibria

Suppose that both types of principal offer an identical compensation scheme $\mathcal{C}$ to implement the action a_H. Then $\mathcal{C}$ does not dependent on the actual monitoring cost of the principal and the arrangement $\mathcal{C}$ does not transmit any information about the principal's private information. Hence, the agent's posterior assessment that he is contracting with a principal of type c_1 is δ (respectively, $1-\delta$ for a type c_2.) His expected utility, if he chooses action a_H is then given as

$$\delta\Big[p_1\mathcal{V}(I) + (1-p_1)\mathcal{V}(J)\Big] + (1-\delta)\Big[p_2\mathcal{V}(I) + (1-p_2)\mathcal{V}(J)\Big] - \mathcal{K}(a_H).$$

Consider now the behavior of a principal when deciding on his monitoring policy. Sequential rationality with respect to his monitoring decision requires that he trades off the payment to the agent in case of no monitoring and the sum of the payment to the agent and his monitoring cost in case he monitors. If we consider a principal with cost c_i who monitors with probability p_i, his expected implementation cost is given by

$$p_i(I + c_i) + (1 - p_i)J.$$

Sequential rationality then imposes the following incentive constraints on the monitoring behavior of a principal of type c_i:

1. If $J - I < c_1$ then $p_1 = 0, \quad p_2 = 0$.
2. If $J - I = c_1$ then $p_1 \in [0,1], \quad p_2 = 0$.
3. If $J - I \in (c_1, c_2)$ then $p_1 = 1, \quad p_2 = 0$.
4. If $J - I = c_2$ then $p_1 = 1, \quad p_2 \in [0,1]$.
5. If $J - I > c_2$ then $p_1 = 1, \quad p_2 = 1$.

The restrictions show that a principal with lower cost monitors the agent's behavior with a higher probability than a principal with higher cost. That is, $p_1 \geq p_2$. Moreover, if $p_1 = 1$ and $p_2 = 0$, the agent's payment has to satisfy $J - c_2 \leq I \leq J - c_1$. The principal with cost c_1 monitors with certainty, so he prefers to choose the payment J as high as possible, for he always pays I and J contributes positively to the agent's expected utility. Consequently, he would set $J = I + c_2$. The principal with monitoring cost c_2, however, prefers to choose I as high as possible, i.e., $I = J - c_1$, for he always pays J. Without loss of generality, we can therefore set either $I = J - c_1$ or $I = J - c_2$. Then the incentive constraints above hold trivially, if we require:

$$\text{either (1)} \quad p_1 \in [0,1], \quad p_2 = 0 \quad \text{if} \quad I = J - c_1, \qquad (ICP_1)$$

$$\text{or (2)} \quad p_1 = 1, \quad p_2 \in [0,1] \quad \text{if} \quad I = J - c_2. \qquad (ICP_2)$$

The principal's problem of minimizing his implementation cost then splits into two programs. Problem $(\hat{P}_1)$ corresponds to case (1) and reads as

$$\text{Choose } (I, p_1) \text{ to minimize } (I) \text{ subject to}$$

$$\delta\Big[p_1\mathcal{V}(I) + (1-p_1)\mathcal{V}(I+c_1)\Big] + (1-\delta)\Big[\mathcal{V}(I+c_1)\Big] - \mathcal{K}(a_H) \geq \bar{U} \qquad (IRC)$$

$$\delta\Big[p_1\mathcal{V}(I) + (1-p_1)\mathcal{V}(I+c_1)\Big] + (1-\delta)\Big[\mathcal{V}(I+c_1)\Big] - \mathcal{K}(a_H) \geq$$
$$\delta\Big[p_1\mathcal{V}(\underline{I}) + (1-p_1)\mathcal{V}(I+c_1)\Big] + (1-\delta)\Big[\mathcal{V}(I+c_1)\Big] - \mathcal{K}(a_L) \qquad (ICA)$$

Similarly, case (2) leads to the following program $(\hat{P}_2)$:

$$\text{Choose } (I, p_2) \text{ to minimize } (I) \text{ subject to}$$

$$\delta\Big[\mathcal{V}(I)\Big] + (1-\delta)\Big[p_2\mathcal{V}(I) + (1-p_2)\mathcal{V}(I+c_2)\Big] - \mathcal{K}(a_H) \geq \bar{U} \qquad (IRC)$$

$$\delta\Big[\mathcal{V}(I)\Big] + (1-\delta)\Big[p_2\mathcal{V}(I) + (1-p_2)\mathcal{V}(I+c_2)\Big] - \mathcal{K}(a_H) \geq$$
$$\delta\Big[\mathcal{V}(\underline{I})\Big] + (1-\delta)\Big[p_2\mathcal{V}(\underline{I}) + (1-p_2)\mathcal{V}(I+c_2)\Big] - \mathcal{K}(a_L) \qquad (ICA)$$

Now define $\hat{p}_1 = \delta \cdot p_1$ and $\hat{p}_2 = (1-\delta)\cdot p_2 + \delta$. Then $p_1 \in [0,1]$ iff $\hat{p}_1 \leq \delta$ and $p_2 \in [0,1]$ iff $\delta \leq \hat{p}_2$. In view of these definitions, the programs $(\hat{P}_i)$, $i = 1, 2$, simplify to:

$$\text{Choose } (I, \hat{p}_i) \text{ to minimize } (I) \text{ subject to}$$
$$\hat{p}_i\mathcal{V}(I) + (1-\hat{p}_i)\mathcal{V}(I+c_i) - \mathcal{K}(a_H) \geq \bar{U}$$
$$\hat{p}_i\mathcal{V}(I) + (1-\hat{p}_i)\mathcal{V}(I+c_i) - \mathcal{K}(a_H) \geq$$
$$\hat{p}_i\mathcal{V}(\underline{I}) + (1-\hat{p}_i)\mathcal{V}(I+c_i) - \mathcal{K}(a_L)$$

This minimization problem is equivalent to program $(\hat{P})$ in Section 2.2. Let $\bar{\delta}_1 := \hat{p}_1^*$ and $\bar{\delta}_2 := \hat{p}_2^*$ be the solutions of the problems $(\hat{P}_1)$ and $(\hat{P}_2)$, respectively. Using the second part of Proposition 2.2, we conclude that $\bar{\delta}_1 < \bar{\delta}_2$ since $c_1 < c_2$. Thus, the principal's minimization problems $(\hat{P}_1)$ and $(\hat{P}_2)$ have the following solutions (C_i^*, p_i^*), $i = 1, 2$:

1. If $\delta \geq \bar{\delta}_1$ then $p_1^* = \dfrac{\bar{\delta}_1}{\delta}$, $p_2^* = 0$ and $I^*(c_1) + c_1 = J^*(c_1)$.
2. If $\delta \leq \bar{\delta}_2$ then $p_1^* = 1$, $p_2^* = \dfrac{1}{1-\delta}\cdot(\bar{\delta}_2 - \delta)$ and $I^*(c_2) + c_2 = J^*(c_2)$.

The solutions of the minimization program $(\hat{P}_1)$ and $(\hat{P}_2)$ seem to be candidates for perfect Bayesian equilibria. However, it remains to show which out-of-equilibrium beliefs actually support these solutions. Consider therefore the profit Π_i of a principal of type c_i in the case of a solution 1. and 2., respectively:

1. If $\delta \geq \bar{\delta}_1$ then $\Pi_1 = B(a_H) - \left[I^*(c_1) + c_1\right]$ and $\Pi_2 = B(a_H) - \left[I^*(c_1) + c_1\right]$.
2. If $\delta \leq \bar{\delta}_2$ then $\Pi_1 = B(a_H) - \left[I^*(c_2) + c_1\right]$ and $\Pi_2 = B(a_H) - \left[I^*(c_2) + c_2\right]$.

As we know from Proposition 2.2, the agent's payment $I^*(c)$ is decreasing in monitoring cost. Hence, a principal with low monitoring cost c_1 prefers to choose the solution of program $(\hat{P}_2)$, for $I^*(c_1) > I^*(c_2)$. He will offer the corresponding compensation scheme C_2^* as long as the agent's prior belief is smaller than $\bar{\delta}_2$. However, even if δ is higher than this critical value, the principal of type c_1 is better off with the scheme C_2^*. To see this, restrict the possible range of monitoring probabilities in program $(\hat{P}_2)$ to $p_2 \geq 0$ and let $I^*(c_2, \delta)$ denote the solution of the problem, if $\delta > \bar{\delta}_2$. Then the solution for p_2 is a corner solution, $p_2^* = 0$. Continuity of the $I^*(c_2, \delta)$ in δ ensures that there exists a value $\bar{\nu}_2 > \bar{\delta}_2$ such that for all $\delta \in (\bar{\delta}_2, \bar{\nu}_2]$

$$B(a_H) - I^*(c_2, \delta) - c_1 \geq B(a_H) - I^*(c_1) - c_1.$$

Hence, if the agent's assessment δ exceeds the critical value $\bar{\nu}_2$, the principal with low monitoring cost c_1 prefers to offer the compensation scheme C_1^*.

Similarly, we can consider the preferences of a principal with high monitoring cost. Proposition 2.2 implies that the agent's payment in case of no monitoring, $J^*(c) + c$, is increasing in c. So the profit of a principal of type c_2 with respect to the solution of program $(\hat{P}_1)$ is greater than the one with respect to the solution of program $(\hat{P}_2)$. Hence, if $\delta \geq \bar{\delta}_1$, he prefers to offer the arrangement C_1^* instead of C_2^*. According to the argument above, a principal with cost c_2 prefers to offer the arrangement C_2^*, if the agent's assessment that he is contracting with a principal of type c_1 is smaller than some critical value. That is, there exists a value $\bar{\nu}_1 < \bar{\delta}_1$ such that for all $\delta \in [\bar{\nu}_1, \bar{\delta}_1)$

$$B(a_H) - I^*(c_1, \bar{\nu}_1) - c_1 \geq B(a_H) - I^*(c_2) - c_2.$$

Hybrid equilibria

We conclude the discussion on the structure of equilibria and show that there cannot exist hybrid equilibria. Suppose, therefore, that one type of principal randomizes in equilibrium between the compensation schemes C_1^* and C_2^*, whereas the other type chooses C_i^*, $i = 1$ or 2. Let $\Pi_i(C, p_i^*(C))$ denote the net profit of a principal of type c_i, if he offers the arrangement C. Then we can distinguish two cases.

First, assume that the principal with cost c_1 is indifferent between C_1^* and C_2^*. Then the following conditions have to be satisfied:

$$\Pi_1(C_1^*, p_1^*(C_1^*)) = \Pi_1(C_2^*, p_1^*(C_2^*)), \tag{3}$$
$$\text{and} \quad \Pi_2(C_2^*, p_2^*(C_2^*)) > \Pi_2(C_1^*, p_2^*(C_1^*)). \tag{4}$$

Equation (3) requires that the principal with cost c_1 randomizes between C_1^* and C_2^*. Equation (4) guarantees that the principal with cost c_2 prefers to offer C_2^*. The discussion on separating equilibria shows that if the principal with cost c_2 would offer the arrangement C_1^*, he would never monitor the agent and his expected net profit would be

$$\Pi_2(C_1^*, p_2^*(C_1^*)) = \Pi_1(C_1^*, p_1^*(C_1^*)).$$

But this implies that the expected net profit of a principal with higher monitoring cost is higher than the one for a principal with lower cost, if both offer the same compensation scheme C_2^*. However, this contradicts the result on the payoff structure in pooling equilibria.

It remains to study the case in which the principal with higher monitoring cost c_2 randomizes between C_1^* and C_2^*, whereas the other type chooses C_1^*. Then equilibrium requires

$$\Pi_2(C_1^*, p_2^*(C_1^*)) = \Pi_2(C_2^*, p_2^*(C_2^*)), \tag{5}$$
$$\text{and} \quad \Pi_1(C_1^*, p_1^*(C_1^*)) > \Pi_1(C_2^*, p_1^*(C_2^*)). \tag{6}$$

As we have seen before, a principal with monitoring cost c_1 always monitors the agent, if he would offer the scheme C_2^* and his expected net profit is

$$\Pi_1(C_2^*, p_1^*(C_2^*)) = \Pi_2(C_2^*, p_2^*(C_2^*)) + (c_2 - c_1). \tag{7}$$

Moreover, the discussion on the payoff structure in a pooling equilibrium shows, that

$$\Pi_1(C_1^*, p_1^*(C_1^*)) = \Pi_2(C_1^*, p_2^*(C_1^*)), \tag{8}$$
$$\text{or} \quad \Pi_1(C_1^*, p_1^*(C_1^*)) = \Pi_2(C_1^*, p_2^*(C_1^*)) + (c_2 - c_1). \tag{9}$$

Again, the equations (5) to (8), resp. (9) yield a contradiction. Hence, we conclude that there cannot exists a hybrid equilibrium.

4. EXTENSIONS OF THE PRINCIPAL-AGENT MODEL

The purpose of this section is to extend the simple principal-agent game of Section 2 and 3. We argue that several of our simplifying assumptions can be relaxed without affecting the results. First, we consider a set-up in which there are more than two possible types of principal and in which the agent has a continuum of actions available. Second, we consider the case in which the preferences of the agent depend nontrivially on the principal's monitoring cost.

Let T denote the set of principal's types (costs) where $T \subset \Re_+$ is assumed to be finite. We index $T = \{c_1, \ldots, c_n\}$ so that $c_i < c_{i+1}$. Let A denote a compact and convex set of actions available to the agent. First, consider the case in which the principal's monitoring cost is common knowledge and in which the principal can commit to his monitoring policy at the time of contracting. Then the principal's problem can be described as follows. Let $(a, I, J, p) \in A \times [\underline{I}, \infty) \times [\underline{I}, \infty) \times [0,1]$ be the set of pairs of compensation schemes (a, C) and monitoring probabilities p such that the agent is willing to work for the principal and will find it optimal to choose action $a \in A$. Then the principal of type c_i chooses $(a_i^*, I_i^*, J_i^*, p_i^*)$ in order to maximize his net benefit. Thus, the principal has to solve the following maximization program:

$$\begin{aligned}
&\text{Choose } (a, I, J, p) \text{ to maximize } \mathcal{B}(a) - \left[p(I + c_i) + (1-p)J\right] \quad \text{subject to} \\
&\quad p\mathcal{V}(I) + (1-p)\mathcal{V}(J) - \mathcal{K}(a) \geq \bar{U} \\
&\quad p\mathcal{V}(I) + (1-p)\mathcal{V}(J) - \mathcal{K}(a) \geq p\mathcal{V}(\underline{I}) + (1-p)\mathcal{V}(J) - \mathcal{K}(a') \quad \text{for all } a' \in A.
\end{aligned}$$

This program can be solved in a standard contract theoretical framework. Let (a_i^*, C_i^*, p_i^*) denote a solution of this program. We make the following assumption

(A): Suppose that the principal's cost $c_i \in T$ is common knowledge at the time of contracting and that the principal can commit to monitoring at the time of contracting. Then we assume that every solution of the principal's maximization program depends on his cost, i.e.

$$(a_i^*, C_i^*, p_i^*) \neq (a_j^*, C_j^*, p_j^*) \quad \text{for all } c_i, c_j \in T.$$

Assumption (A) simply says that the principal's type has some influence on the solution of his maximization program. The next proposition shows that under assumption (A) the inability to make commitment leads to a decrease in the amount of information transmitted in equilibrium.

Proposition 4.1: *Suppose that assumption (A) holds. If the principal's monitoring cost is private information, the amount of information transmitted in equilibrium depends on the principal's ability to commit to his monitoring policy. In particular,*

1. *if commitment is possible, the only equilibrium is a separating one,*
2. *if commitment is not possible, the only equilibrium is a pooling one.*

The proof of this proposition is along the lines of the argumentation in Section 3 and can be found in Appendix B. Moreover, in Appendix B we characterize the structure of equilibrium in the case of commitment, respectively non-commitment.

We finish this section and consider a principal-agent game in which the agent's preferences depend nontrivially of the principal's monitoring cost. As an example, we assume that the principal's private information determines how likely monitoring would be informative. A principal's monitoring technology is specified as follows. If the agent chooses an action a and the principal monitors, his observed information can take two values: $\{a, \emptyset\}$, where $\emptyset$ denotes observation "nothing". Let $\varrho \in (0,1)$ denote the quality of the principal's monitoring technology, that is, with probability ϱ the principal's observation is informative. Let $c > 0$ denote the cost of monitoring.

In the case in which the principal's monitoring technology is common knowledge and commitment to monitoring at the time of contracting is not possible, the principal has to solve the following minimization program, if he wishes to implement action a_H:

$$
\begin{aligned}
&\text{Choose } (I, J, p) \text{ to minimize } p\big[\varrho(I+c) + (1-\varrho)(J+c)\big] + (1-p)J \quad \text{subject to} \\
&\quad p\big[\varrho\mathcal{V}(I) + (1-\varrho)\mathcal{V}(J) + (1-p)\mathcal{V}(J) - \mathcal{K}(a_H) \geq \bar{U} \\
&\quad p\big[\varrho\mathcal{V}(I) + (1-\varrho)\mathcal{V}(J) + (1-p)\mathcal{V}(J) - \mathcal{K}(a_H) \geq \\
&\qquad\qquad p\big[\varrho\mathcal{V}(\underline{I}) + (1-\varrho)\mathcal{V}(J) + (1-p)\mathcal{V}(J) - \mathcal{K}(a_L) \\
&\quad \text{and} \quad \varrho\big[J - I\big] = c
\end{aligned}
$$

Set $\tilde{p} = p\varrho$ and $\tilde{c} = c/\varrho$. Then the principal's problem is identical to the problem in Section 2.2 with the additional constraint $\tilde{p} \leq \varrho$. Using the results in Section 2 and 3 we can then prove the following proposition:

Proposition 4.2: *If the principal's private information determines how likely his monitoring is informative but commitment to monitoring is not possible at the time of contracting, the principal does not transmit his information in equilibrium.*

Proof: *See Appendix C.*

5. A MORE GENERAL CLASS OF SIGNALLING PROBLEMS

So far we discussed the role of commitment in the context of a principal-agent relationship with a privately informed principal. The analysis of the preceding sections shows that the informational value of the principal's monetary incentive scheme offered to the agent depends on his ability to commit to monitoring. The intention of this section is to extend this result to a more general class of signalling problems. In particular, we will examine general conditions under which the inability by an informed player to commit to his announcement for an action, he performs simultaneously with the uninformed player's response, leads to a decrease in the amount of information transmitted in equilibrium.

We consider the following class of signalling problems between an informed player, called the principal and an uninformed player, called the agent. The principal, having observed some private information, his type, sends a message, called a contract, to the agent. A contract specifies an action to be taken by the principal and a transfer payment from the principal to the agent for each pair of actions taken by the two parties. The agent then decides whether to accept or reject the contract. If he rejects, he receives some exogenously specified reservation utility. If he accepts the contract, both players simultaneously choose an action. We establish the following notations and assumptions:

T : a finite set of types for the principal, $T = \{t_1, \ldots, t_n\}$ so that $t_i < t_{i+1}$ for $i = 1, \ldots, n-1$. It is convenient to treat different types of the principal as different players.

δ : prior probabilities over the principal's types, i.e. $\delta = (\delta_1, \ldots, \delta_n) \in [0,1]^n$ such that $\sum_{i=1}^{n} \delta_i = 1$.

A : the set of actions available to the agent when choosing his action. We assume that A is a compact real interval.

B : the set of actions available to the principal. He performs an action $b \in B$ simultaneously with the uninformed player's action. We assume that B is a compact real interval.

Y : the set of transfer payments from the principal to the agent. We assume that Y is a compact real interval.

An outcome of the game is a tuple $(t, y, a, b) \in T \times Y \times A \times B$. The payoffs to the principal and to the agent are denoted $u_1(t, y, a, b)$ and $u_2(t, y, a, b)$, respectively, when the outcome is (t, y, a, b). We assume that:

$u_1(t, y, a, b)$ can be written as $g(y, a) - k(t, b)$, where (1) $g : Y \times A \to \Re$ is continuous, strictly decreasing in $y \in Y$ and strictly increasing in $a \in A$, and (2) $k : T \times B \to \Re$ is non-negative and increasing in $b \in B$ for each $t \in T$.

$u_2(t, y, a, b)$ is continuous and strictly increasing in $y \in Y$ and strictly decreasing and convex in $a \in A$ for each $t \in T$. Moreover, $\partial^2 u_2 / \partial a \partial b \geq 0$ and $\partial u_2 / \partial a$ is a decreasing function in the principal's type t.

The assumption that $\partial u_2 / \partial a$ is increasing in b implies that a higher action b makes a higher action a more desirable for the agent. $\partial u_2 / \partial a$ decreasing in t ensures that the agent's best response is decreasing in the principal's type: The lower t is, the higher the action the agent is willing to choose (see Cho/Sobel [1990] and their assumption A3).

Let M denote the set of all functions $m : A \times B \to Y$ which determine the transfer payments from the principal to the agent conditional on their actions. $m \in M$ is called an incentive scheme. m specifies the agent's income conditional on future observations about the players' actions. Let $\alpha \in \Delta(A)$ and $\beta \in \Delta(B)$ denote mixed actions for the agent and the principal, where $\Delta(A)$ and $\Delta(B)$ denote the sets of probability distributions with finite support on A and B, respectively. Then a contract offered by the principal is a tuple (m, β). To simplify the notation, we define for all $t \in T$ expected payoffs

$$EU_1(t,m,\alpha,\beta) = \sum_{(a,b)\in A\times B} u_1(t,m(a,b),a,b)\alpha(a)\beta(b),$$
$$EU_2(t,m,\alpha,\beta) = \sum_{(a,b)\in A\times B} u_2(t,m(a,b),a,b)\alpha(a)\beta(b).$$

We study two cases of the signalling problem described above: In the first case, the principal is able to make a commitment to his subsequent action at the time of contracting; in the second case, he is not. The following assumption about the structure of the function $k(\cdot,\cdot)$ for different types of principal is crucial in what follows:

(A1) If $b < b'$, $b, b' \in B$, then $k(t,b') - k(t,b)$ is strictly increasing in $t \in T$.

Assumption (A1) states that if two actions b and b' yield the same payoff to some type t of principal, i.e. $u_1(t,y,a,b) = u_1(t,y',a,b')$, and b' is greater than b, then all higher types $t' > t$ prefer to take the lower action b, for $u_1(t',y,a,b) > u_1(t',y',a,b')$. Condition (A1) is a familiar assumption in the standard theory of signalling games (see e.g. Cho/Sobel [1990] and their assumption A4) and is related to the single-crossing condition. It ensures that for a given transfer payment $y \in Y$ higher types are more willing to announce lower actions than lower types of principal.

Assumption (A1) plays an important role in our analysis for the following two reasons: First, in the game in which the principal can commit to his action b at the time of contracting - the case of a standard signalling game - (A1) or some form of this condition is necessary in order to obtain separating equilibria, as Cho/Sobel [1990] noted (see also Mailath [1987]). Second, in the game in which the principal's announcement for an action is not binding at the time of performance, (A1) is sufficient in order to obtain pooling equilibria: It ensures (together with another assumption) that whenever different types of principal would offer different incentive schemes, each type of principal would have an incentive to imitate another type (see the discussion below).

We now specify two games Γ^1 and Γ^2 according to the principal's ability or inability to commit to his (mixed) action β and define the corresponding equilibrium concepts. In Γ^1, called the "Commitment Game" we assume that the principal can commit to his action β at the time of contracting. In Γ^2, called the "Non-Commitment Game" we assume that the principal's announcement for an action β is not binding at the time of performance.

The game Γ^1 then has three stages:

1. Nature chooses the principal's type $t_i \in T$ with probability δ_i.
2. The principal offers a contract (m,β).
3. The agent chooses a (mixed) action α.

The strategy for a principal of type $t_i \in T$ in the three-stage game consists of a choice of an incentive scheme $m(t_i)$ and a (mixed) action $\beta(t_i)$. The agent's strategy consists of the choice of an action α. The agent's decision is contingent on the principal's incentive scheme and the action proposed, i.e. $\alpha : M \times \Delta(B) \to \Delta(A)$. We are interested in perfect Bayesian equilibria.

In our framework, such an equilibrium consists of $n+1$ strategies - one for each type of principal and the agent - and beliefs $\tilde{\delta} : M \times \Delta(B) \rightarrow \Delta(T)$ for the agent about the principal's types such that (i) for each player his strategy maximizes his expected utility given beliefs and the other players' strategies; (ii) the agent's belief are derived from Bayes' rule given the equilibrium strategies. That is, we assume that the agent updates his prior beliefs about the principal's types using Bayes' rule after observing the contract proposed. An equilibrium γ^1 then is a mapping

$$\gamma^1 : t \longmapsto (m(t), \beta(t), \alpha(m,\beta), \tilde{\delta}(m,\beta)) \quad \text{such that for all } t \in T$$

$$(m(t), \beta(t)) \in \arg\max_{(m,\beta)\in M\times\Delta(B)} EU_1(t, m, \alpha(m,\beta), \beta), \qquad (ICP_1)$$

$$supp\ \alpha(m,\beta) \subset \arg\max_{\alpha\in\Delta(A)} \sum_{i=1}^{n} \tilde{\delta}(m,\beta)(t_i)\ EU_2(t_i, m(t), \alpha, \beta(t)), \qquad (ICA)$$

and beliefs $\tilde{\delta} = (\tilde{\delta}_1, \ldots, \tilde{\delta}_n)$ are consistent with Bayes' rule.

An equilibrium then must satisfy two types of conditions. First, the principal offers an incentive scheme and an action which maximizes his expected utility, given the agent's response. That is, (ICP_1) holds. Second, the agent must work in the principal's interests, given the contract offered. That is, the incentive compatibility constraint (ICA) holds. We make the following assumption (A2):

(A2) There exists a separating equilibrium in the "Commitment Game".

Although, in general, this assumption should be the result of some comprehensive analysis, (A2) can be justified in this context for two reasons: First, in view of assumption (A1), the existence of only separating equilibria would follow, if we would impose some form of condition which ensures that no type of principal prefers to imitate the lowest type (see e.g. Cho/Sobel [1990]). Second, the purpose of this section is to give general conditions which imply that information transmission is correlated with commitment ability rather than to prove the existence of separating equilibria for some class of signalling problems involving commitment.

Next we characterize the structure of the "Non-Commitment Game" Γ^2 and give conditions under which only pooling equilibria exist. The game Γ^2 has three stages:

1. Nature chooses the principal's type $t_i \in T$ with probability δ_i.
2. The principal offers an incentive scheme m.
3. The agent chooses a (mixed) action α. At the same time, the principal chooses a (mixed) action β.

As for the "Commitment Game" Γ^1, we can characterize strategies for each player in Γ^2 and define the concept of sequential equilibria. There are two differences to the definition above: First, the agent when choosing his optimal action, can base his decision only on the incentive scheme offered by the principal. That is, his action and his belief about principal's type are a function only of the incentive scheme proposed but not of the principal's (mixed) action β.

Second, the principal's inability to commit to the choice of an action β at the time of contracting requires sequential rationality with respect to this decision. Hence, a sequential equilibrium for the "Non-Commitment Game" imposes an incentive compatibility constraint on the principal's behavior. In particular, an equilibrium γ^2 then is a mapping

$$\gamma^2 : t \longmapsto (m(t), \beta(t,m), \alpha(m), \tilde{\delta}(m)) \quad \text{such that for all } t \in T$$

$$m(t) \in \arg\max_{m \in M} EU_1(t, m, \alpha(m), \beta(t,m)), \qquad (ICP_1)$$

$$supp\ \beta(t,m) \subset \arg\max_{b \in B} EU_1(t, m(t), \alpha(m), b), \qquad (ICP_2)$$

$$supp\ \alpha(m) \subset \arg\max_{\alpha \in \Delta(A)} \sum_{i=1}^{n} \tilde{\delta}(m)(t_i)\ EU_2(t_i, m(t), \alpha, \beta(t,m)), \qquad (ICA)$$

and beliefs $\tilde{\delta} = (\tilde{\delta}_1, \dots, \tilde{\delta}_n)$ are consistent in the sense of Kreps/Wilson [1982].

Of course, if an equilibrium γ^1 of the "Commitment Game" would satisfy the principal's constraints (ICP_2), this equilibrium would also be an equilibrium in the "Non-Commitment Game". Hence, in order to obtain no separating equilibria in the game Γ^2, it is necessary to assume that for every separating equilibrium γ^1 at least one of the principal's incentive constraints (ICP_2) is violated. In particular, it must be the case that in every separating equilibrium γ^1 at least one type of principal is indifferent between choosing some action b or b'.

We now give a condition under which an equilibrium γ^2 of the "Non-Commitment Game" cannot be a separating one: Fix an equilibrium of Γ^2. Following Cho/Sobel [1990], we say that $b \in B$ is a "pooled action", if more than one type of principal uses b with positive probability. Then we can state the following result.

Proposition 5.1: *Let γ^2 be an equilibrium of the "Non-Commitment Game". If γ^2 has a pooled action, then γ^2 cannot be separating.*

Proof: *See Appendix D.*

Note that a pooling equilibrium in the context of the "Non-Commitment Game" refers to a situation in which all types of principal offer an **identical incentive scheme** $m \in M$. Hence, Proposition 5.1 does not state the canonical claim that a pooling equilibrium cannot be separating.

The intuition of the proof of Proposition 5.1 is as follows. Let γ^2 be an equilibrium of the "Non-Commitment Game" in which a principal of type $t_i \in T$ offers the incentive scheme $m_i = m(t_i)$ and chooses a (mixed) action $\beta_i = \beta(t_i, m_i)$. Let $\alpha_i = \alpha(m_i)$ denote the agent's equilibrium strategy. Then define

$$G_i(b) = \sum_{a \in A} g(m_i(a,b), a)\alpha_i(a)$$

for each $b \in supp\ \beta_i$, $t_i \in T$. Thus, $G_i(b)$ is the gross utility of a principal of type t_i in equilibrium, if he chooses action b. For $b' \notin supp\ \beta_i$ define

$$G_i(b') = G_i(b) - k(t_i, b) + k(t_i, b') \quad \text{for } b \in supp\ \beta(t_i).$$

$G_i(b')$ then denotes the principal's gross utility he must receive in order to be indifferent between playing his equilibrium (mixed) action and some other action. Figure 1 shows the gross utilities $G_i(b)$, respectively $G_j(b)$, for two types of principal t_i and t_j, $t_i < t_j$. In Figure 1, $G_i(b_{ij}) = G_j(b_{ij})$, i.e. the indifference curves intersect at some point $b_{ij} \in B$. Assumption (A1) requires that the slope of a principal's indifference curve increases with his type. Moreover, the indifference curves are upwards sloping because a higher action by a principal implies higher cost.

Figure 1

Figure 1 provides a geometric description of the proof of Proposition 5.1. For suppose that the equilibrium γ^2 has a pooled action $b \in B$ and that the two types of principal t_i and t_j choose b with positive probability. Then γ^2 cannot be separating. To see why, consider the following cases: 1. Suppose that the pooled action b is smaller than b_{ij}. But then the principal of type t_j has an incentive to deviate from his equilibrium strategy, for he can increase his utility by imitating type t_i: he offers the incentive scheme of type t_i and then chooses b with certainty. 2. If the pooled action b is greater than the intersection point b_{ij}, the principal of type t_i can exploit his cost advantages by offering the incentive scheme of type t_j and then choosing b with probability one. 3. If the intersection point b_{ij} is a pooled action, then each types of principal is indifferent between imitating the other type or playing his equilibrium strategy.

Note, that the converse of Proposition 5.1 is not true. To see this, consider a pooling equilibrium of the "Non-Commitment Game" in which all types of principal offer the same incentive scheme $m \in M$. Then Figure 2 provides an example in which a higher type of principal chooses a lower action $b \in B$ than a lower type (this follows from assumption (A1)) [7].

Figure 2

Proposition 5.1 provides a simple condition that ensures the non-existence of separating equilibria in the "Non-Commitment Game". In order to guarantee that only pooling equilibria exist, we then have to assume that if different types of principal intend to offer different incentive schemes, there exists a pooled action $b \in B$ they choose in stage 3 of Γ^2. One such assumption is the following one:

Let $\alpha(t, m, \beta)$ be the set of best responses of the agent to the incentive scheme $m \in M$ when he knows that the principal's type is $t \in T$ and expects the principal's (mixed) action to be β, i.e.

$$\alpha(t, m, \beta) = \arg\max_{a \in A} EU_2(t, m, a, \beta).$$

Let $\beta(t, m, \alpha)$ be the set of best responses of the principal of type t when he offers the incentive scheme m and expects the agent's (mixed) action to be α, i.e.

$$\beta(t, m, \alpha) = \arg\max_{b \in B} EU_1(t, m, \alpha, b).$$

Let $\alpha(t, m)$ and $\beta(t, m)$ be (mixed) actions of the agent and, respectively, the principal such that

$$\alpha(t, m) \subset \alpha(t, m, \beta(t, m)),$$
$$\beta(t, m) \subset \beta(t, m, \alpha(t, m)).$$

(A3) For at least two types of principal $t_i, t_j \in T$, there exists an action $b' \in B$ such that the following condition is satisfied: For every incentive scheme $m \in M$ and action $b \in B$, $b \neq b'$, there exists an incentive scheme $m' \in M$ such that for all (mixed) actions $\alpha(t_n, m')$ and $\alpha(t', m)$

$$EU_1(t', m', \alpha(t_n, m'), b') > EU_1(t', m, \alpha(t', m), b) \quad \text{for } t' \in \{t_i, t_j\}.$$

Assumption (A3) ensures that a principal of type t_i, respectively t_j, would prefer to choose an action b' and be treated like the highest type of principal t_n rather than separate from other types (see also Cho/Sobel [1990] and their assumption A6).

Assumption (A3) then implies that no separating equilibrium in the "Non-Commitment Game" can exist. For suppose that this claim is false. Let γ^2 be a separating equilibrium. Then we claim that b' is a pooled action of γ^2. We argue to a contradiction. Suppose that b' is not a pooled action of γ^2. Consider a principal of type $t' \in \{t_i, t_j\}$ and let $EU_1(t')^*$ denote his utility in equilibrium γ^2. Suppose that at stage 1 the principal of type t' deviates by offering the incentive scheme m' given by his equilibrium scheme m and equilibrium action $\beta(t', m)$ and assumption (A3). Suppose that following this deviation the agent has belief μ and chooses action $\alpha(\mu, m')$. Then we claim that $\alpha(\mu, m')$ is higher than $\alpha(t_n, m')$. To see this, consider a best response $\beta(t_n, m')$ of type t_n. According to assumption (A1), each type of principal $t < t_n$ then prefers to choose the highest action $b \in supp\ \beta(t_n, m')$, given the agent's response $\alpha(t_n, m')$. Since $\partial u_2/\partial a$ is increasing in b and decreasing in t, the agent's best response $\alpha(t, m')$ is increasing in t. Hence, $\alpha(\mu, m') \geq \alpha(t_n, m')$ for every probability distribution μ over T. As a consequence, if the principal of type t' offers m' and chooses the action b', his utility is

$$EU_1(t', m', \alpha(\mu, m'), b') \geq EU_1(t', m', \alpha(t_n, m'), b') > EU_1(t')^*.$$

This contradicts the assumption that m and $\beta(t', m)$ is an equilibrium strategy of the principal of type t'. Hence, the assumption that b' is not a pooled action of γ^2 must be wrong. By Proposition 5.1, γ^2 then cannot be separating. This, however, contradicts the assumption that γ^2 is separating.

To see how the extention in this section relates to the analysis in previous sections, assume that the set B of actions available to the principal is a two-point action space $B = \{mo, nomo\}$. In the example, the agent's utility is independent of the principal's type and monitoring induces the agent to choose a higher action a. Then assumption (A1) is satisfied because we assumed that $c_t = k(t, mo)$ is strictly increasing in $t \in T$ and $k(t, nomo) = 0$ for all $t \in T$. Moreover, assumption (A2) holds by the assumptions in the previous sections. Finally, assumption (A3) is valid, for all types of principal would like to be treated like the one with the highest monitoring cost: If they offer the contract $(I^{**}(c_n), J^{**}(c_n))$, they would prefer to monitor with certainty (their monitoring costs are lower than the premium the principal with the highest monitoring cost pays in case of no monitoring) and the agent's remuneration in case of monitoring is decreasing in monitoring cost (see Proposition 2.2).

It is important to note that the following modification of the principal-agent relationship with monitoring options by the principal doesnot satisfy the assumption (A3): Assume that the principal's action set B is the interval $[0,1]$, and let $b \in B$ be the probability that he monitors the agent's choice of an action. Then $b = 0$ ($b = 1$) refers to the case of no monitoring (respectively, monitoring with certainty). In this game, a principal can design his incentive scheme m conditional on his monitoring probability. Hence, if (a_i^*, C_i^*, p_i^*) is an equilibrium strategy of a principal with private information on his monitoring cost c_i in the commitment case (see Section 4), this strategy is also an equilibrium strategy of the principal in the case of non-commitment: He can simply promise the agent an infinitely high payment in case he deviates from the action p_i^*. Hence, he chooses p_i^* with certainty in equlibrium, independent of his commitment ability. Assumption (A) in Section 4 then guarantees that a principal can reveal his private information also in the case of non-commitment. Assumption (A3) is violated in this game, because no type of principal can benefit by imitating another type: Each type chooses his optimal action in B with certainty. That is, there never exists a pooled action in equilibrium.

Footnotes

[1] Note, that the principal monitors the agent with positive probability, for the agent's payment cannot be made conditional on the outcome.

[2] Or, equivalently, the principal forces the agent to pay his monitoring.

[3] Myerson uses an approach which is axiomatic and co-operative game theoretic. The articles by Maskin and Tirole consider a principal-agent relationship in which the agent's action is directly observable by the principal. They distinguish between the cases where the principal's private information is an argument of the agent's utility function ("common values") and those where it is not ("private values").

[4] Laffont and Tirole consider a two-period model in which the principal updates the compensation scheme after observing the agent's first period performance. They assume that the principal

cannot commit not to use this information in the second period. The article by Fudenberg and Tirole studies a model in which the principal cannot commit to a contract that will not be renegotiated after the agent's choice of an action and before the observation of the action's consequences.

[5] We sometimes use the notation (I, J) to denote a compensation scheme C.

[6] Note, that the principal chooses a monitoring probability $p(C) \in [0, 1]$, if the compensation scheme C is accepted by the agent. In the following, we sometimes abuse notation and let $p = p(C)$ denote the principal's monitoring probability, if it is clear from the context that C is offered.

[7] Of course, the equilibrium for the "Non-Commitment Game" illustrated in Figure 2 is an equilibrium also in the "Commitment Game".

APPENDIX A

Proof of Proposition 2.1:

Suppose $p = 1$. Then I is determined by the equation $\mathcal{V}(I) = \bar{\mathcal{U}} + \mathcal{K}(a_H)$. Now let $J = I$. Then the individual rationality constraint (IRC) holds for all $\hat{p} \in [0,1]$. Since $\mathcal{V}(I) - \mathcal{K}(a_H) > \mathcal{V}(\underline{I}) - \mathcal{K}(a_L)$, there exists some $\hat{p} \in (0,1)$ such that the incentive constraint (ICA) still holds. But then the principal acn increase his profit:

$$\Pi(1) = \mathcal{B}(a_H) - I - c < \mathcal{B}(a_H) - I - \hat{p}c = \Pi(\hat{p})$$

Moreover, $p = 0$ contradicts the individual incentive constraint (ICA). Hence, the solution of the principal's minimization problem (P) implies $p \in (0,1)$.

Note, that problem (P) is the minimization of a linear objective function subject to concave constraints. If we regard $v = \mathcal{V}(I)$ and $w = \mathcal{V}(J)$ as the principal's control variables, we can convert problem (P) into the minimization of a convex function subject to linear constraints. Hence, the Kuhn-Tucker theorem yields necessary and sufficient conditions for optimality. In particular, there exist $\lambda \geq 0$, $\mu \geq 0$ such that any solution (v, w, p) of the principal's minimization program is a solution to the following problem:

$$\begin{aligned} \min_{v,w,p} \quad \mathcal{L} := \; & p(h(v) + c) + (1-p)h(w) - \lambda\big[pv + (1-p)w - \mathcal{K}(a_H) - \bar{\mathcal{U}}\big] \\ & - \mu\big[pv + (1-p)w - \mathcal{K}(a_H) - p\underline{v} - (1-p)w + \mathcal{K}(a_L)\big], \end{aligned}$$

where $h(\cdot) = \mathcal{V}(\cdot)^{-1}$, $\underline{v} = \mathcal{V}(\underline{I})$. An interior solution (v, w, p) of this problem (P) then satisfies the following conditions:

$$\left(\frac{\partial \mathcal{L}}{\partial v}\right) \quad p\big[(\lambda + \mu) - h'(v)\big] = 0, \tag{1}$$

$$\left(\frac{\partial \mathcal{L}}{\partial w}\right) \quad (1-p)\big[\lambda - h'(w)\big] = 0, \tag{2}$$

$$\left(\frac{\partial \mathcal{L}}{\partial p}\right) \quad h(w) - h(v) - c - \lambda w + (\lambda + \mu)v - \mu\underline{v} = 0. \tag{3}$$

Suppose that $\lambda = 0$. Then equation (2) yields a contradiction. Hence, $\lambda > 0$. Suppose that $\mu = 0$, then $h(v) = h(w)$ by equation (1) and (2), thus $v = w$. However, equation (3) then yields a contraction. Hence, $\mu > 0$ and $h'(v) > h'(w)$, thus $I > J$. Moreover, the following conditions have to be satisfied:

$$pv + (1-p)w - \mathcal{K}(a_H) - \bar{\mathcal{U}} = 0, \tag{4}$$

$$p\big[v - \underline{v}\big] - \mathcal{K}(a_H) + \mathcal{K}(a_L) = 0. \tag{5}$$

In equilibrium the solution (v, w, p, λ, μ) is determined by the equations (1)-(5). Converting these equations such that (I, J) are the principal's control variables shows that the solution (I, J, p) of problem (P) is uniquely determined. Moreover, we have:

$$\frac{\partial I}{\partial c} \cdot A + \frac{\partial \lambda}{\partial c} \cdot B + \frac{\partial \mu}{\partial c} \cdot B = 0 \tag{1'}$$

$$\frac{\partial J}{\partial c} \cdot C + \frac{\partial \lambda}{\partial c} \cdot D = 0 \tag{2'}$$

$$\frac{\partial \lambda}{\partial c} \cdot E + \frac{\partial \mu}{\partial c} \cdot F = 1 \tag{3'}$$

$$\frac{\partial p}{\partial c} \cdot E + \frac{\partial I}{\partial c} \cdot G = 0 \tag{4'}$$

$$-\frac{\partial p}{\partial c} \cdot H + \frac{\partial J}{\partial c} \cdot K = 0 \tag{5'}$$

where $A = \mathcal{V}''(I)$, $B = (\lambda + \mu)^{-2}$, $C = \mathcal{V}''(J)$, $D = \lambda^{-2}$, $E = \mathcal{V}(I) - \mathcal{V}(J)$, $F = \mathcal{V}(I) - \mathcal{V}(\underline{I})$, $G = p\mathcal{V}'(I)$, $H = \mathcal{V}(J) - \mathcal{V}(\underline{I})$, $K = (1-p)\mathcal{V}'(J)$.

Use (4') to substitute for $\frac{\partial p}{\partial c}$ *in (5'). Also, one can use (3') to substitute for* $\frac{\partial \mu}{\partial c}$ *in (1') and then use (2') to substitute for* $\frac{\partial \lambda}{\partial c}$ *in (1'). Then one finds:*

$$\frac{\partial I}{\partial c} \cdot \frac{G}{E} + \frac{\partial J}{\partial c} \cdot \frac{K}{H} = 0 \tag{6'}$$

$$\frac{\partial I}{\partial c} \cdot A + \frac{\partial J}{\partial c} \cdot \frac{CBH}{DE} = \frac{B}{E} \tag{7'}$$

Substituting equation (6') in (7') for $\frac{\partial J}{\partial c}$ *or* $\frac{\partial I}{\partial c}$*, resp., proves the first part of the claim of the proposition. Substituting this result in equation (4') proves the remaining part.*

Q.E.D.

APPENDIX B

Proof of Proposition 4.1:

We use the following notation:

- δ : *prior probabilities over the principal's monitoring cost, i.e.* $\delta = (\delta_1, \ldots, \delta_n) \in [0,1]^n$ *such that* $\sum_{i=1}^n \delta_i = 1$.
- $\tilde{\delta}$: *the agent's posterior beliefs* $\tilde{\delta} = (\tilde{\delta}_1, \ldots, \tilde{\delta}_n) \in [0,1]^n$ *over the principal's monitoring cost after the principal has proposed a contract* $(a, \mathcal{C})$ *and a monitoring probability* p, $\sum_{i=1}^n \tilde{\delta}_i = 1$.

1. The case of commitment

Similar to the argumentation in Section 3.1, the agent's utility is independent of the actual type of principal, given a contract (a, C) and a monitoring policy p is offered:

$$\sum_{i=1}^{n} \tilde{\delta}_i \left[p\mathcal{V}(\mathcal{C}(a, mo)) + (1-p)\mathcal{V}(\mathcal{C}(a, nomo)) - \mathcal{K}(a)\right] =$$
$$\left[p\mathcal{V}(\mathcal{C}(a, mo)) + (1-p)\mathcal{V}(\mathcal{C}(a, nomo)) - \mathcal{K}(a)\right] \quad \text{for all } a \in A$$

Hence, the n independent optimization programs, one for each principal of type c_i are identical to the optimization programs in the case without private information. Assumption (A) then implies that these programs have different solutions (a_i^*, C_i^*, p_i^*). Hence, the only equilibrium in the case of private information is the solution $(a_1^*, C_1^*, p_1^*, \ldots, a_n^*, C_n^*, p_n^*)$. These strategies are supported by the following beliefs $\tilde{\delta}^*$:

$$\tilde{\delta}_i^*(a_i^*, C_i^*, p_i^*) = 1 \quad \text{for all } i = 1, \ldots, n \quad \text{and} \quad \tilde{\delta}_i^*(a, C, p) \in [0,1] \quad \text{otherwise.}$$

2. The case of non-commitment

First, we characterize the structure of a pooling equilibrium. Second, we prove that there cannot exist a separating equilibrium. Third, the case of a hybrid equilibrium is analyzed.

Suppose that in equilibrium the principal's compensation scheme does not reveal information about his monitoring cost. Let (a^*, C^*) denote this arrangement. Sequential rationality requires that each type of principal chooses his monitoring policy as follows:

1. If $J^* - I^* < c_1$ then $p_i = 0$ for all $i = 1, \ldots, n$.
2. If $J^* - I^* = c_i$ then $p_j = 1$ for $j < i$, $p_i \in [0,1]$, $p_j = 0$ for $j > i$.
3. If $J^* - I^* \in (c_i, c_{i+1})$ then $p_j = 1$, for $j \leq i$, $p_j = 0$ for $j > i$.
4. If $J^* - I^* > c_n$ then $p_1 = 1$, for all $i = 1, \ldots, n$.

Note that for a given action of the agent, the marginal cost of the payment I^* (J^*) is increasing (decreasing) in the principal's type: If $J^* - I^* \in (c_i, c_{i+1})$ for $i \in \{1, \ldots, n-1\}$, then a principal of type $c_j \leq c_i$ prefers to choose the payment J^* as high as possible, whereas a principal of type $c_j > c_i$ prefers to have I^* as high as possible.

We now claim that in equilibrium one type of principal is indifferent between monitoring or not. To see this, suppose this claim is false. Let $J^* - I^* \in (c_i, c_{i+1})$ for $i \in \{1, \ldots, n-1\}$, supported by the agent's posterior beliefs $\tilde{\delta}^*$. Let C_i denote the arrangement (I, J) with $J - I = c_i$ which minimizes the agent's payment I subject to the constraints that the agent signs the contract and chooses action a^*. Then if $\tilde{\delta}^*(C_i) = \delta$, the benefit of a principal of type $c_j > c_i$ is higher when offering C_i instead of C^*, a contradiction. If, on the other hand side, $\tilde{\delta}_k(C_i) < \delta_k$ for some $k \in \{1, \ldots, n\}$, there exists an index $l \in \{1, \ldots, n\}$, with $\tilde{\delta}_l(C_i) > \delta_l$ such that a principal of type c_l prefers C_i to C^* if $l > j$ or C_{i+1} to C^* if $l \leq j$, a contradiction.

Hence, if (a^*, C^*) constitutes an equilibrium, then $J^* = I^* + c_i$ for one $i \in \{1, \ldots, n\}$. Thus, we have to solve the following optimization program for each $i \in \{1, \ldots, n\}$:

$$\begin{aligned}
&\text{Choose } (a_i^*, I_i^*, \tilde{p}_i^*) \text{ to maximize } \ \mathcal{B}(a) - I \ \text{ subject to}\\
&\quad \tilde{p}_i \mathcal{V}(I) + (1-\tilde{p}_i)\mathcal{V}(I + c_i) - \mathcal{K}(a) \geq \bar{U}\\
&\quad \tilde{p}_i \mathcal{V}(I) + (1-\tilde{p}_i)\mathcal{V}(I + c_i) - \mathcal{K}(a) \geq\\
&\qquad\qquad \tilde{p}_i \mathcal{V}(\underline{I}) + (1-\tilde{p}_i)\mathcal{V}(I + c_i) - \mathcal{K}(a') \quad \text{for all } a' \in A,\\
&\quad \tilde{p}_i \in [\Delta_{i-1}, \Delta_i], \quad \text{where } \Delta_i = \delta_1 + \ldots + \delta_i.
\end{aligned}$$

The solution (a_i^*, I_i^*, p_i^*) of this maximization program together with the conditions $p_j^* = 1$ for $c_j < c_i$ and $p_j^* = 0$ for $c_j > c_i$ then form a sequential equilibrium. To see this, suppose that some other compensation scheme (a, C) is offered by the principal. If the agent's out-of-equilibrium beliefs $\tilde{\delta}_j^*$ are arbitrary small for all $j \in \{1, \ldots, n\}$, $j \neq i$, these beliefs support the arrangement (a_i^*, C_i^*) in equilibrium: (a_i^*, C_i^*) is the solution of the maximization problem of a principal with cost c_i (see Section 2.2) and a principal with cost c_j, $c_j \neq c_i$ cannot gain by offering an other scheme (a, C) (see the argumentation in Section 3.2).

As in Section 3.2, we now prove by contradiction that there cannot exist a separating equilibrium. Suppose first that there exists a separating equilibrium in which different types of principal's offer different compensation schemes. Let (a_i, C_i) denote the scheme of a principal with cost c_i. According to the argumentat in Section 3.2, the principal's net benefit is

$$\Pi_i(a_i, C_i) = \mathcal{B}(a_i) - C_i(a_i, mo) - c_i.$$

Now consider a principal with cost c_j who offers the arrangement of a principal with cost c_i. If $c_j > c_i$, he would not monitor the agent's behaviour. If, on the other hand, $c_j < c_i$, he would prefer to monitor with certainty. Hence

$$\Pi_j(a_i, C_i) = \begin{cases} \Pi_i(a_i, C_i) + (c_i - c_j) & \text{if } c_j < c_i \\ \Pi_i(a_i, C_i) & \text{otherwise} \end{cases}$$

Then for every pair (c_i, c_j) of types of principal the assumption of a separating equilibrium yields a contradiction.

Suppose now that a hybrid equilibrium exists in which some but not all types of principal $\tilde{T} \subset T$ offer one single compensation scheme (a, C). Let (I, J) denote the agent's payments under this arrangement. According to the characterization of a pooling compensation scheme, one type of principal $c_i \in \tilde{T}$ must be indifferent between monitoring or not, i.e. $I + c_i = J$. But then an argument similar to the one before yields a contradiction.

Q.E.D.

APPENDIX C

Proof of Proposition 4.2:

Consider first the solution of the principal's program in the case in which his quality of monitoring ϱ is common knowledge. If the solution of the principal's program is an interior solution, $(p^{**}_{\varrho}(c), I^{**}_{\varrho}(c), J^{**}_{\varrho}(c))$ has the following properties (see Proposition 2.2):

$$p^{**}_{\varrho}(c) = p^{**}(c/\varrho)/\varrho,\ I^{**}_{\varrho}(c) = I^{**}(c/\varrho), \text{ and } J^{**}_{\varrho}(c) = I^{**}_{\varrho}(c) + c/\varrho$$

Moreover, if the solution of the principal's program is a corner solution with $p^{**}_{\varrho}(c) = 1$, then $(I^{**}_{\varrho}(c), J^{**}_{\varrho}(c))$ is a solution of the principal's program when commitment is possible.

To prove the claim of the proposition, suppose first that for two monitoring qualities ϱ_1 and ϱ_2 the principal's programs lead to different monitoring probabilities. Then it follows from Proposition 3.2. that if the monitoring quality ϱ is private information for the principal, $\varrho \in \{\varrho_1, \varrho_2\}$, no separating nor hybrid equilibrium can exist. Suppose, alternatively, that the principal's programs for ϱ_1 and ϱ_2 result in identical monitoring probabilities. This implies that in both cases the principal monitors with certainty and hence, compensation schemes are identical. Now, if the principal's monitoring quality is private information and can take either the value ϱ_1 or ϱ_2, both types of principal will offer the same arrangement. Hence, in equilibrium only pooling compensation schemes are possible.

Q.E.D.

APPENDIX D

Proof of Proposition 5.1:

We argue to a contradiction. Let γ^2 be a separating equilibrium of the "Non-Commitment Game" in which a principal of type $t_i \in T$ offers the incentive scheme $m_i = m(t_i)$ and chooses a (mixed) action $\beta_i = \beta(t_i, m_i)$. Let $\alpha_i = \alpha(t_i, m_i)$ denote the agent's equilibrium strategy. Then define

$$G_i(b) = \sum_{a \in A} g(m_i(a,b), a)\alpha_i(a)$$

for each $b \in supp\ \beta(t_i)$, $t_i \in T$. Thus, $G_i(b)$ is the gross utility of a principal of type t_i in equilibrium if he chooses action b. For $b' \notin supp\ \beta(t_i)$ define

$$G_i(b') = G_i(b) - k(t_i, b) + k(t_i, b') \quad \text{for } b \in supp\ \beta(t_i).$$

$G_i(b')$ then denotes the principal's gross utility he must receive in order to be indifferent between playing his equilibrium (mixed) action and some other action.

Suppose that for two types of principal t_i, $t_j, t_i < t_j$ there exists a critical value $b_{ij} \in B$ such that $G_i(b_{ij}) = G_j(b_{ij})$. Then, by the assumption (A1) and the properties of the principal's cost-function $k(\cdot,\cdot)$ we infer that

$$G_i(b) > G_j(b) \quad \text{for all } b < b_{ij},$$
$$G_i(b) < G_j(b) \quad \text{for all } b > b_{ij}.$$

To see this, consider the case in which $b < b_{ij}$. Then $G_i(b) - k(t_i, b) = G_i(b_{ij}) - k(t_i, b_{ij})$ by definition of the function $G_i(\cdot)$, hence by assumption (A1) $G_i(b) - k(t_j, b) > G_i(b_{ij}) - k(t_j, b_{ij})$. Since $G_i(b_{ij}) = G_j(b_{ij})$ and $G_j(b_{ij}) - k(t_j, b_{ij}) = G_j(b) - k(t_j, b)$ by definition of $G_j(\cdot)$, we conclude $G_i(b) - k(t_j, b) > G_j(b) - k(t_j, b)$ which proves the claim. The proof for $b > b_{ij}$ follows in the same way.

Now, let $b \in B$ be an action, both types of principal choose with positive probability in equilibrium.

1. If $b < b_{ij}$, then t_j benefits from imitating t_i, for his payoff is $G_i(b) - k(t_j, b)$ which is greater than his equilibrium payoff $G_j(b) - k(t_j, b)$.

2. If $b > b_{ij}$, then $G_j(b) - k(t_i, b)$ is greater than $G_i(b) - k(t_i, b)$ and, hence, type t_i has an incentive to imitate t_j.

3. If $b = b_{ij}$, then both types of principal are indifferent between playing their equilibrium strategy and imitating the other type because $G_i(b) = G_j(b)$.

In summary, γ^2 cannot be a separating equilibrium, which contradicts the assumption.

Q.E.D.

REFERENCES

[1] Banks, J. and J. Sobel [1985]: "Equilibrium Selection in Signalling Games". *Econometrica, Vol.55, 647-661*

[2] Baron, D. and D. Besanko [1984]: Regulation, Asymmetric Information and Auditing. *Rand Journal of Economics, Vol. 15, 447-470*

[3] Cho, I. and D. Kreps [1987]: "Signalling Games and Stable Equilibria". *Quarterly Journal of Economics, Vol.102, 179-221*

[4] Cho, I. and J. Sobel [1990]: "Strategic Stability and Uniqueness in Signalling Games". *Journal of Economic Theory, Vol. 50, 381-413*

[5] Fudenberg, D. and J. Tirole [1990]: Moral Hazard and Renegotiation in Agency Contracts. *Econometrica, Vol.58, 1279-1319*

[6] Hart, O. and J. Moore [1988]: "Incomplete Contracts and Renegotiation". *Econometrica, Vol. 56, 755-785*

[7] Jost, P. [1991]: "Monitoring in Principal-Agent Relationships". *Journal of Institutional and Theoretical Economics, Vol. 147, 517-538*

[8] Laffont, J. and Tirole, J. [1988]: "The Dynamics of Incentive Contracts". *Econometrica, Vol.56, 1153-1175*

[9] Mailath, G. [1987]: "Incentive Compatibility in Signaling Games with a Continuum of Types. *Econometrica, Vol. 55, 1349-65*

[10] Maskin, E. and J. Tirole [1990]: The Principal-Agent Relationship with an Informed Principal: The Case of Private Values. *Econometrica, Vol.58, 379-409*

[11] Maskin, E. and J. Tirole [1992]: The Principal-Agent Relationship with an Informed Principal, II: Common Values. *Econometrica, Vol.60, 1-42*

[12] Myerson, R. [1983]: "Mechanism Design by an Informed Principal". *Econometrica, Vol.51, 1767-1797*

[13] Reinganum, J. and L. Wilde [1985]: Income Tax Compliance in a Principal-Agent Framework. *Journal of Public Economics, Vol.26, 1-18*

[14] Reinganum, J. and L. Wilde [1986]: Equilibrium Verification and Reporting Policies in a Model of Tax Compliance. *International Economic Review, Vol.27 (3), 739-760*

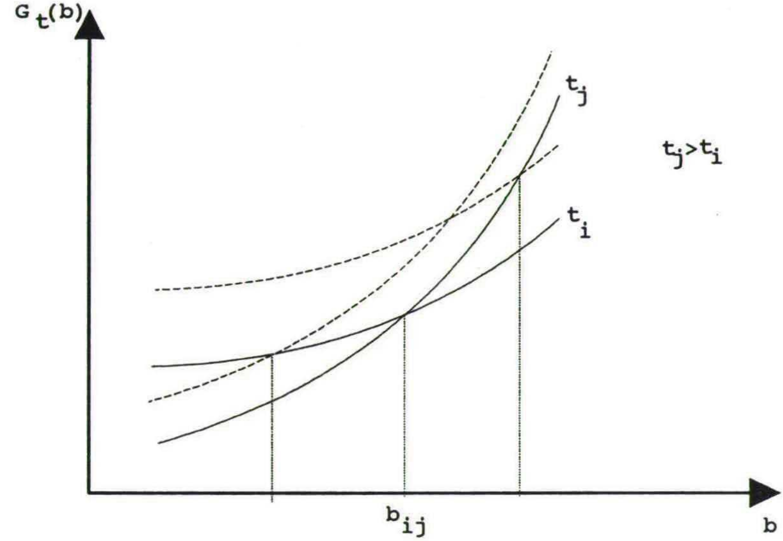

Figure 1

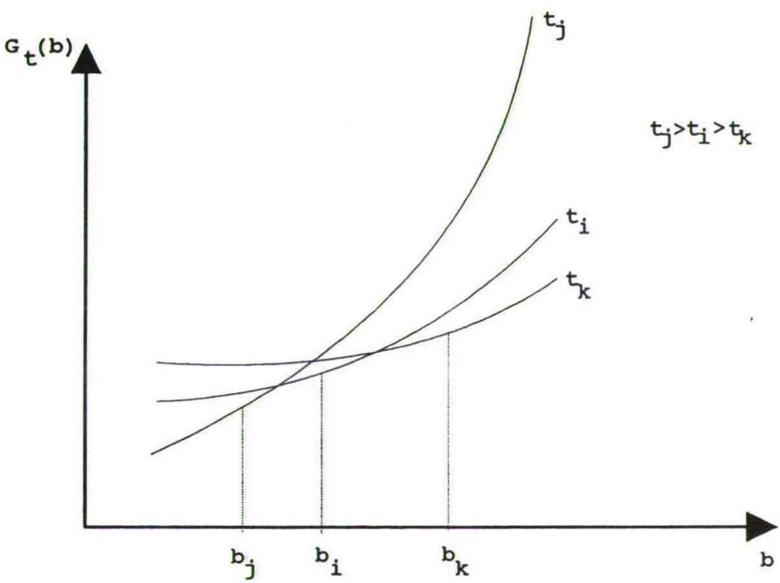

Figure 2

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