Are you a Good Employee or Simply a Good Guy? Influence Costs and Contract Design

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Abstract

We develop a principal-agent model with a moral hazard problem in which the principal has access to a hard signal (the level of output) and a soft signal (the supervision signal) about the agent's level of effort. We show that the agent's ability to manipulate the soft signal increases the cost of implementing the efficient equilibrium, leading to wage compression when the influence cost is privately incurred by the agent. When manipulation activities negatively affect the agent's productivity through the level of output, the design of influence-free contracts that deter manipulation may lead to high-powered incentives. This result implies that high-productivity workers face incentive schemes that are more sensitive to hard evidence than those faced by their low-productivity counterparts. In that context, the principal will tolerate influence for low-productivity workers but not for high-productivity workers. We also find that in the case of productivity-based costs, it may be optimal for the principal not to supervise the agent, even if supervision is costless (JEL D23, D82).

Keywords: principal-agent model with supervision, contract design, influence activities, manipulation, productivity-based influence costs, power of incentives.

1 Introduction

Recent financial scandals including the Madoff's case of felony and the distortion of budget figures by the Greek government, raise the question of the manipulability of information. In this article we study this issue in a principal-agent setup, in which the agent is given the possibility to influence the principal's evaluation of his work by manipulating certain pieces of information through the use of influence activities that distort the principal's evaluation of his performance if the principal engages in supervision.[1]

A comprehensive analysis of the manipulability of information requires a precise understanding of the relation between the concepts of hard and soft information. In the finance literature, hard information is defined as being quantitative (Berger et al., 2001; Stein, 2002; Petersen, 2004; Liberti and Mian, 2009). Hard information is assumed to be easy to store, to be transmitted in impersonal ways and to be independent of the collection process; all these features making it a priori difficult for hard information to be manipulated. Further, research on supervision and delegation in principal-agent models refer to hard information as being verifiable (Tirole, 1986) whereas soft information is considered to be unverifiable (Baliga, 1999; Faure-Grimaud, Laffont and Martimort, 2003). In these models, a signal is unverifiable whenever it cannot be observed by a third party (the "judge"). Manipulability of information implies that soft information can be distorted whereas hard information can simply be hidden.

In the current article, we consider a principal-agent model, in which the principal has access to both, hard and soft information about the agent's level of effort. We assume that hard information cannot be manipulated whereas soft information is subject to manipulation attempts. In our framework, agents do not distort or hide their own pieces of information but undertake influence activities in order to manipulate the soft signal collected by the principal. This way of modeling influence is related to the work of Mullainathan, Schwartzstein and Shleiffer (2008) who model the concept of associative thinking. In their framework, individuals classify situations into categories, and transfer the informational content of a given signal from situations in a category where it is useful to those where it is not.[2] Applying this concept to our model, the principal who dedicates time to monitor the agent will find it difficult to distinguish the following positive pieces of information "*The agent is a hard-working (good) employee*" and "*The agent is a good person*". These pieces of information belong to two different categories, work abilities and personality, and the difficulty for the principal is to disentangle signals that concern the contribution of their employee to the firm and the ones that relate to personal characteristics. Specifically, we model influence as a reduced form of coarse thinking by considering that the principal suffers from biased information processing à la Bénabou and Tirole (2002). As a result, the principal may misperceive a negative soft signal about the level of effort of the agent as being positive.[3]

[1] Hereafter, we use the feminine pronouns for the principal and masculine for the agent.

[2] Persuasion has also been modeled using an informational approach (Milgrom and Roberts, 1986; Dewatripont and Tirole, 1999).

[3] Although our model of manipulation is closely related to the analysis of influence activities in the organizational literature, an alternative interpretation of our model is related to the distortion of quantitative information (e.g., documents falsification).

The consideration of both hard and soft signals relates our analysis to the literature on subjective evaluations (Baker, Gibbons and Murphy, 1994; MacLeod, 2003). In our model, similarly to the analysis developed in Baker, Gibbons and Murphy (1994), the principal can propose contingent contracts that depend on a hard signal (determined by the level of production) as well as on a soft signal, which provides additional information about the level of effort of the agent. However, in contrast with the model of Baker, Gibbons and Murphy (1994) and the general framework of MacLeod (2003), we assume that both the principal and the agent agree on the value of the soft signal so that the signal can be treated as if it were verifiable. As a result, we can disentangle the issues related to the unverifiability of subjective evaluations (MacLeod, 2003) from the issues related to the manipulability of such evaluations.

1.1 The costs and benefits of influence activities

Influence activities have been identified as actions completed by organizational members in order to bias the decisions of managers toward more pay and promotions (Milgrom, 1988; Milgrom and Roberts, 1988, 1992).[4] As a general principle, this analysis suggests that influence costs can be reduced by limiting the discretion of decision makers for those decisions that have a significant impact on the distribution of rents inside the organizations but that have minor impact on the firm's profits.[5]

In our model, we focus on optimal contracts rather than organizational design as a mechanism to reduce influence costs. Specifically, we derive incentive contracts that implement the high level of effort by the agent (hereafter, we refer to this effort as the efficient level of effort). We assume that influence activities are unverifiable so that the principal cannot prevent influence simply by punishing attempts to manipulate soft signals. In our model, influence activities tend to reduce aggregate welfare by increasing information asymmetry between principal and agent. As a result, the agent's ability to manipulate the soft signal increases the cost of implementing the efficient level of effort.

Our approach differs from the model developed by Maggi and Rodríguez-Clare (1995) in which agents can distort the principal's private information in order to reduce information asymmetry. In their setting, information distortion may actually allow for the falsification of information in equilibrium, and as a result, may increase aggregate welfare. Relatedly, Lacker and Weinberg (1989) consider a sharecropping model

In this paper, we do not focus on the latter interpretation, although the majority of our results can be interpreted from this perspective.

[4] Also, notice that influence costs have been considered as a key element of the theory of the firm (Gibbons, 2005).

[5] Milgrom (1988) also mentions the use of compensation schemes as one of the possible instruments with which to reduce influence activities. In particular, the author puts forward that the compression of wage differentials between current jobs and promotion jobs is an effective strategy for reducing incentives to influence the manager's promotion decision.

which focus on optimal risk-sharing when agents have the possibility to misreport the volume of the crop. The authors find that, in general, the principal should induce some misreporting in equilibrium in order to improve risk-sharing.

1.2 Incentive Schemes under Influence

We first characterize the optimal contracts when influence costs are privately incurred by the agent. We show that the cost of implementing the efficient equilibrium increases as the soft signal becomes more manipulable and influence activities are more pervasive. This occurs because in the presence of influence activities the principal relies on less informative signals and must, as a result, increase the variance of wages in order to keep incentives intact. This implies that a larger rent will have to be paid to the risk-averse agent in order to ensure that the participation constraint holds. This result follows from Kim (1995) after showing that the efficiency of the information structure decreases in the manipulability of the soft signal.

We also show that optimal wages become more compressed and less volatile as the soft signal becomes more manipulable. In addition, more weight is given to the hard signal in the payment scheme in the presence of highly manipulable soft signals. These results are closely related to the sufficient statistic theorem (Holmström, 1979; Banker and Datar, 1989) in which incentive contracts must include all the signals that are informative about the agent's level of effort. Indeed, incentive schemes will be less responsive to the soft signal as it becomes more manipulable (and therefore less informative). Given that wages are less responsive to the soft signal, both the range of possible wages as well as the variance of wages decrease. This finding is related to the result established in MacLeod (2003) in which wage compression occurs when the measures of agent performance are subjective. However, the mechanism behind wage compression in MacLeod (2003) is different from ours. In the previous model, wage compression follows from the fact that subjective evaluations are unverifiable so that the optimization problem of the principal includes the additional constraint that both the agent and the principal truthfully reveal their private signals. Wage compression is also present in the model of influence activities in promotion decisions of Milgrom (1988) in which the reduction in wage differentials between available jobs is found to be an optimal response against influence activities.

1.3 Optimal Contracts and the Value of the Firm

We extend our analysis to the case in which influence activities entail costs in terms of the firm productive activities as is suggested by the initial definition in Milgrom (1988).

> "That time of course is valuable; if it were not wasted in influence activities, it could be used for directly productive activities or simply consumed as leisure."

In this context of *productivity-based* influence costs, the principal will have to choose between accepting some influence activities in equilibrium or designing influence-free contracts that eliminate manipulation attempts. In our framework, we must emphasize that not all optimal contracts can be replicated by influence-free contracts for which agents have no incentives to influence the principal. To understand why an influence-proof principle does not apply let us consider the situation in which the cost for employees of initiating influence activities is arbitrarily close to zero. In that case influence-free contracts would only consist of a fixed wage. The fixed wage contract is the only type of contract that fully eliminates the agent's incentives to boost his actual contribution. However, fixed wage contracts do not satisfy the incentive-compatibility constraint since in this case the agent would not exert the high level of effort in equilibrium. Therefore, influence-free contracts cannot always implement the efficient equilibrium.

The design of influence-free contracts relies on two possible strategies to dissuade influence activities. The first one consists of designing incentive contracts that are less responsive to the soft signal so as to reduce the expected benefits associated with influence activities. This first strategy would induce even greater wage compression and weaker incentives in the case of *productivity-based* influence costs than in the case of private influence costs. This follows from the fact that the cost of initiating influence activities is lower for the agent when it is not privately incurred, making the manipulation of soft signals potentially more appealing. As a result, under this strategy, influence-free contracts are likely to induce low-powered incentives and a low level of effort.

The second strategy, which is actually followed by the principal in equilibrium, consists of increasing the opportunity cost associated with influence activities by increasing the incentives associated with the hard signal. In that case, influence activities become less attractive as they reduce the probability that the agent will get the high payment associated with a high level of performance on the hard signal. As a result of this second strategy, the principal may be willing to design high-powered incentives contracts to deter influence activities. More specifically, we show that high-powered incentives and influence-free contracts are more likely to be offered to high-productivity agents for which influence is especially costly in terms of firm productivity than to low-productivity agents. Also, we show that the incentive contracts of high-productivity agents tend to be more responsive to the hard signal compared with low-productivity agents.

Finally, we show that, in the case of *productivity-based* influence costs, the principal may decide not to supervise the agent in equilibrium, even though supervision is costless. This is the case because, in our setting, supervision gives the agent the opportunity to engage in destructive influence activities.

In this version of our model, the substitutability between hard and soft information follows from the fact that improving the soft signal through influence activities is detrimental to the value of the hard signal. It is interesting to note that the mechanism underlying the substitutability between the two types of signals differs from our model with private influence costs. In the model with private influence costs as well as in Baker, Gibbons and Murphy (1994), the substitutability between signals follows from the fact that highly precise hard signals are sufficient to ensure the implementation of the efficient equilibrium independently of the reception of soft signals.

The rest of the paper is organized as follows. We present our model in the case of rational supervisors in Section 2 and solve the corresponding model in Section 3. The analysis of the model with influence is developed in Section 4. We extend our model for the case in which the influence activity is costly for the organization in Section 5. We conclude in Section 6. All proofs are available in the appendix.

2 The Model

2.1 Description of Actions and Payoffs

We consider a principal-agent model with three stages described as follows.

- In Stage 1, the principal [she] sets a contract $\mathbf{w}$ that will be used to pay the agent [he] in the last stage of the game. The contract is contingent on the level of production in the organization $y \in Y := \{0, 1\}$, which yields revenues $R(y)$ for the principal, where $R(1) > R(0) \geq 0$. This level of production is a hard and non-manipulable signal of the agent's level of effort.

  In Stage 1, the principal also decides whether to engage in supervising the agent ($s = 1$) or not ($s = 0$) in order to obtain the additional signal (v) about the agent's level of effort.[6] The contract can be made contingent on this supervision signal $v \in V := \{B, G\}$ which costs $\phi_s \geq 0$ to the principal and it is collected in Stage 3. This piece of information can be interpreted as a soft signal about the employee's performance where B means: *the agent is a lazy (bad) employee* and G means: *the agent is a hard-working (good) employee.*

- In Stage 2, the agent decides whether to exert a high level of effort ($e = e_H$) or a low level of effort ($e = e_L$) on a productive task, where $e_H > e_L$. The level of effort (e) exerted by the agent on the productive task affects the level of production in the organization (y). The cost of effort on the

[6] This part of the game resembles models of costly acquisition of additional signals (Lambert, 1985).

productive task is denoted by $\phi(e) \geq 0$. We denote $\phi_e := \phi(e_H) > 0$ and without loss of generality assume that $\phi(e_L) = 0$.

In Stage 2, the agent also decides whether to undertake an influence activity ($a = 1$) or not ($a = 0$). The private cost of effort associated with influence activities is denoted by $\phi(a) \geq 0$, where $\phi_a := \phi(1) > 0$ and $\phi(0) = 0$.

The objective of the influence activity is to affect the evaluation of the principal with regard to the agent's actual level of effort by distorting the principal's perception (v_s) of the supervision signal (v). Our model builds on the idea that if the principal engages in supervision in Stage 1 and the agent undertakes influence activities then she will not necessarily observe the true value of the supervision signal v. Instead, the principal will observe v_s which refers to the principal's, possibly erroneous, perception of the true signal.[7]

- In Stage 3, the principal cannot observe the level of effort on the productive task. However, the principal observes the level of production as well as the supervision signal if the principal decided to supervise the agent. The principal then pays the agent according to the contract chosen in Stage 1. We assume that the level of output (y) satisfies the condition that $P[y = 0 \mid e = e_L] = P[y = 1 \mid e = e_H] = \rho_y$, where the precision of the hard signal is denoted by $\rho_y \in \left[\frac{1}{2}, 1\right]$. It is assumed that the supervision signal when there is no influence from the agent (i.e. $v_s := v$) satisfies the condition that $P[v = B \mid e = e_L] = P[v = G \mid e = e_H] = \rho_v$, where the precision of the soft signal is denoted by $\rho_v \in \left[\frac{1}{2}, 1\right]$.

Our model can be summarized as follows:

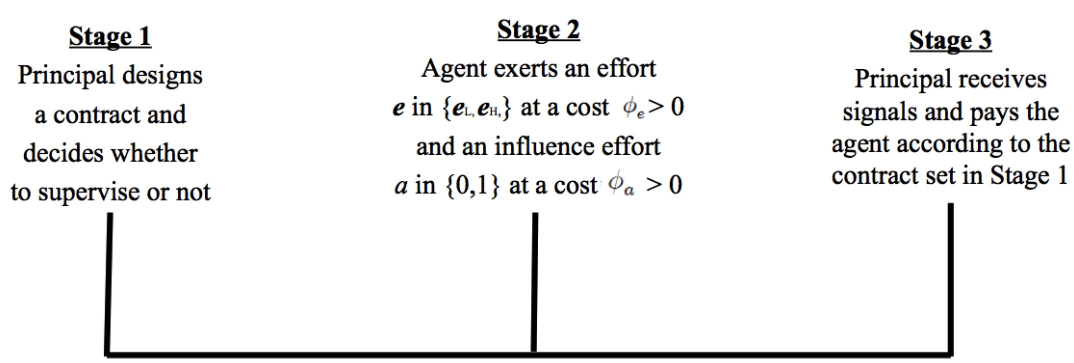

Figure 1. Timeline for the supervision and influence model.

The final payoff for the principal is determined as follows.

[7] The supervision signal can then be interpreted either as subjective evaluation of the supervisor or as quantitative information about the performance of the agent.

$U_P := U(s, v_s, w, y) = R(y) - w_{yv_s} - s\phi_s$, where $y \in \{0,1\}$ indicates the level of production and $s \in \{0,1\}$ denotes whether supervision takes place ($s = 1$) or not ($s = 0$).

The final payoff for the risk-averse agent is determined as follows.

$U_A := U(a, e, v_s, w) = u(w_{yv_s}) - \phi(e) - \phi(a) > 0$ where $u' > \varepsilon > 0$, $u'' < 0$.[8]

We denote $\bar{u} > 0$ the agent's outside option and $w_{yv_s} \in \mathbb{R}$ stands for the wage paid to the agent contingently on receiving signals y and v_s.[9]

After presenting the structure of our model we detail our assumptions as follows.

2.2 Assumptions

The principal does not directly observe the level of effort of the agent on the productive task, $e \in \{e_L, e_H\}$ but she receives a hard signal on the level of effort by observing output (y). The principal may obtain an additional signal about the performance of her subordinate by engaging in supervision activities at a cost. We assume that the supervisor's perception of the soft signal (v_s) can be manipulated by influence activities (a). We model the influence of the agent on his supervisor's assessments as a case of biased attribution (Bénabou and Tirole, 2002) in which the principal may mistakenly perceive a negative signal about her employee as being positive as a result of influence activities. This biased attribution process can be related to the concept of transference for which the characteristic of an agent as a person is associated with his quality as an employee even though in our context *"being a good person"* is not informative about *"being a good employee"* (Mullainathan, Schwartzstein and Schleiffer, 2008).[10] In the following assumption, we refer to $\pi \in [0,1]$ as the bias of the principal. In line with Bénabou and Tirole (2002), we consider that the principal and the agent are fully aware of the bias of the principal. We state these assumptions as follows.

Assumption I (Influence)

If the agent decides to undertake an influence activity in Stage 2 ($a = 1$), then the principal will perceive with probability $\pi \in [0,1]$ any soft signal as if it were good.

With probability $(1 - \pi)$ the principal uses standard Bayesian updating.

In the case of a rational supervisor, $\pi = 0$ so that $v_s := v$.

[8] We assume that the utility of the agent is separable in effort and in the influence cost as used for example in MacLeod (2003).

[9] We abuse notation and assume that if the agent is not being supervised then $v_s = \{\varnothing\}$. This does not mean that the soft signal v can take neutral values.

[10] We can also think of trust and positive reciprocity as important factors in explaining the supervisor's biased perception of the performance of the agent in the presence of influence activities (see Hosmer, 1995).

The bias of the principal $\pi \in [0,1]$ captures the difficulty of the supervisor to disentangle positive influence behaviors ($a = 1$) from positive soft signals ($v = G$). Clearly the existence of this bias creates incentives for the agent to manipulate the soft signal through influence activities.[11]

Assumption A (Awareness of Biases)

Let $\hat{e}$ denotes the level of effort implemented by the principal in equilibrium. The principal updates her belief about the soft signal as follows:

$$\begin{cases} P\left[v = G \mid v_s = G, \hat{e} = e_H\right] = \frac{\rho_v}{\pi(1-\rho_v)+\rho_v} \\ P\left[v = G \mid v_s = G, \hat{e} = e_L\right] = \frac{1-\rho_v}{(1-\rho_v)+\pi\rho_v} \\ P\left[v = G | v_s = B, \hat{e}\right] = 0 \end{cases}$$

This assumption is used in Bénabou and Tirole (2002) and is referred to as metacognition. Under this assumption, the principal knows that perceiving her employee positively ($v_s = G$) may not systematically imply that the soft signal was positive given that, with probability π, the principal being under the influence of the agent ($a = 1$) always perceives the soft signal positively.

One important feature of our model concerns the contractibility of the influence activity. We clarify this point in Assumption O.

Assumption O (Observability of actions and signals)

i) The influence activity ($a \in \{0,1\}$) is observed by the supervisor but it is not verifiable.

ii) The supervision signal v_s is observable by both the agent and the principal.

The first part of Assumption O states that the influence activity is unverifiable by a third party implying that incentive contracts cannot be contingent on the observed action $a \in \{0,1\}$. For example, if you undertake an influence activity and invite your boss for a coffee ($a = 1$) she will naturally observe this action but she will not be able to write any incentives contract using this piece of information.[12] The second part of Assumption O implies that both the principal and the agent agree on the value of signal v_s so that the supervision signal can be treated as if it were verifiable (See MacLeod, 2003).[13] These features of our model

[11] Influence activities could also be interpreted as, for example, document falsification. In that case, the value of $\pi \in [0,1]$ would be interpreted as the agent's ability to falsify the signal.

[12] Also, at the time the agent decides to have a coffee with his boss he does not know his performance on the soft signal. If this were the case, the agent would attempt to influence his boss only after observing $v_s = B$ so that inviting the boss for a coffee would automatically reveal the soft signal ($v = B$) to the principal. This is why, in the timing of our model, influence activities (in Stage 2) precede the collection of the soft signal (v_s) (in Stage 3).

[13] This is the case if we assume that a third party can design a mechanism that would punish the agent and the principal if they do not reveal the same value of the soft signal v_s.

allow us to disentangle the issues related to the fact that subjective evaluations are unverifiable (MacLeod, 2003) from the issues related to the manipulability of such evaluations.

Finally, we assume that the objective of the principal is to implement the high level of effort (we therefore refer to e_H as the efficient level of effort) and study the contract that elicits the efficient level of effort at the lowest possible cost to the principal.[14]

2.3 Definitions and Properties of Optimal Contracts

In this section, we introduce notations and definitions that will be useful to characterize optimal contracts.

We denote by $\mathbf{w} = [w_{1G}, w_{1B}, w_{0G}, w_{0B}]$, where $\mathbf{w} \in \mathbb{R}_+^4$, the contract designed by the principal in Stage 1 according to which the agent will be paid as a function of the hard and the soft signals. In the absence of supervision, the principal does not collect a soft signal and the contract is defined as follows $\mathbf{w}_N = [w_{1\varnothing}, w_{0\varnothing}]$, where $\mathbf{w}_N \in \mathbb{R}_+^2$. We thus denote $w_{yv_s} := w(y, v_s)$ the wage that will be received by the agent if the hard signal is y and the soft signal perceived by the principal is v_s. We denote $\hat{\mathbf{w}}$ ($\hat{\mathbf{w}}_N$) the contracts that implement the efficient level of effort e_H at the lowest possible cost to the principal in the presence (absence) of supervision. We denote by $P_1[P_0]$ the probability vector associated with receiving the payments in $\mathbf{w} = [w_{1G}, w_{1B}, w_{0G}, w_{0B}]$ when the agent is supervised and exerts a high [low] level of effort on the productive task. The probability vector associated with the payments $\mathbf{w}_N = [w_{1,\varnothing}, w_{0,\varnothing}]$ is denoted by $P_1^N[P_0^N]$ when the agent exerts a high [low] level of effort on the productive task.[15]

A principal who suffers from cognitive bias in the perception of the true supervision signal ($\pi > 0$) may decide not to supervise the agent so as to avoid manipulation attempts. However, the soft signal may include additional information on the agent level of effort that the principal may need in order to incentivate the agent to exert a high level of effort. The decision of supervising the agent or not will be determined by comparing the informative value of the soft signal and the cost of its acquisition.

Definition 1 *We say that the supervision signal is valuable to the principal as long as there exists* $(\hat{\mathbf{w}}, \hat{\mathbf{w}}_N) \in \mathbb{R}_+^4 \times \mathbb{R}_+^2$ *that implement* e_H *such that* $\hat{\mathbf{w}}\mathbf{P}_1 - \hat{\mathbf{w}}_N\mathbf{P}_1^N < 0$.

In line with Definition 1, the soft signal is valuable to implement the efficient level of effort when it is informative about the agent's performance (i.e., when it contains pieces of information that can be used to

[14] This assumption can be sustained as long as the revenues for the principal following a high level of production $R(1)$ are sufficiently higher than the principals' revenues following a low level of production $R(0)$. In that case, the expected revenues obtained by the principal from incentivizing the agent to work hard would always compensate for the costs of implementing the high level of effort.

[15] For simplicity we assume that wages are row vectors and probabilities are column vectors so as to avoid the use of transposes.

elicit the agent's level of effort at a lower cost).[16]

Our objective is to characterize the optimal contract that implements e_H in the presence of supervision $\left(\hat{\mathbf{w}} \in \mathbb{R}_+^4\right)$ as well as in the absence of supervision $\left(\hat{\mathbf{w}}_N \in \mathbb{R}_+^2\right)$. To do so, we will use the following definitions that assess the respective weights of the hard and the soft signals as well as the power of incentives. We assess the relative weight of each signal by comparing optimal wages in the situation in which the principal receives conflicting signals $((y, v_s) \in \{(1, B), (0, G)\})$. We also investigate how the difference between these wages (w_{1B} and w_{0G}) changes when there is an increase in a parameter κ (namely, the principal's bias π or the influence cost ϕ_a).

Definition 2 (Respective weights of hard and soft signals)

i) We say that more weight is assigned to the hard (soft) signal in the optimal contract if $w_{0G} < w_{1B}$ *(*$w_{0G} > w_{1B}$*).*

ii) We say that an increase in a parameter (κ) *raises the weight that is assigned to the hard (soft) signal in the optimal contract if* $\frac{\partial}{\partial \kappa}(w_{1B} - w_{0G}) > 0$ *(*$\frac{\partial}{\partial \kappa}(w_{0G} - w_{1B}) > 0$*).*

In the following definition we assess the responsiveness of incentive contracts to hard and soft signals. In particular we state that the *power of incentives* associated with an optimal contract increases in a given signal if the difference between wages following a low value of the signal and wages following a high value of the signal increases. In that respect our definition of the *power of incentives* is related to the concept of wage compression since a reduction in the power of incentives in both hard and soft signals implies wage compression.

Definition 3 (Wage compression and the power of incentives)

i) We say that the power of incentives increases (decreases) in the hard signal (y) *with respect to parameter* (κ) *whenever* $\frac{\partial(w_{1v_s} - w_{0v_s})}{\partial \kappa} > 0$ (< 0) *for any* $v_s \in \{B, G, \varnothing\}$*.*

ii) We say that the power of incentives increases (decreases) in the soft signal (v_s) *with respect to the parameter* (κ) *whenever* $\frac{\partial(w_{yG} - w_{yB})}{\partial k} > 0$ (< 0) *for any* $y \in \{0, 1\}$*.*

3 Rational Supervision

Our benchmark model assumes that the principal is able to identify the soft signal without errors $(\pi = 0)$. In that context, the agent will never engage in an influence activity $(a = 0)$ in Stage 2 given that he will not be able to manipulate the soft signal and distort the principal's beliefs as a result.

[16] In case of costless supervision $(\phi_s = 0)$ it is easy to see that the principal will supervise the agent whenever the precision of the soft signal satisfies the condition that $\rho_v > \frac{1}{2}$.

We analyze how wages are set by the principal in that case and discuss the role of supervision. We denote by $\hat{\mathbf{w}}^R$ $\left[\hat{\mathbf{w}}_N^R\right]$ the optimal contracts that allow the principal to implement the efficient level of effort e_H in the absence of influence ($\pi = 0$) and in the presence [absence] of supervision. Our first proposition characterizes the optimal contract $\hat{\mathbf{w}}^R$ under supervision.

Proposition 1 (Optimal wages under supervision) *If the principal supervises the agent in the model without influence, the optimal contract* $\hat{\mathbf{w}}^R$*that implements the efficient equilibrium satisfies the following conditions:*

- *If* $\frac{1}{2} < \rho_v \leq \rho_y$ *then* $\hat{w}_{0B}^R < \hat{w}_{0G}^R \leq \hat{w}_{1B}^R < \hat{w}_{1G}^R$
- *If* $\frac{1}{2} < \rho_y < \rho_v$ *then* $\hat{w}_{0B}^R < \hat{w}_{1B}^R < \hat{w}_{0G}^R < \hat{w}_{1G}^R$

Our results follow from the fact that wages are non-decreasing in either the hard or the soft signal.[17] That is, $\hat{w}_{1v_s}^R \geq \hat{w}_{0v_s}^R$ for any $v_s \in \{B, G\}$ and $\hat{w}_{yG}^R \geq \hat{w}_{yB}^R$ for any $y \in \{0, 1\}$. Also, the relative weight given to each signal depends on the relative precision of the soft and hard signals. If the soft signal is less precise than the hard signal $\rho_v \leq \rho_y$ then more weight will be assigned to the hard signal in the optimal contract whereas more weight will be assigned to the soft signal if the reverse is true $\rho_v > \rho_y$. In the presence of conflicting signals ($(y, v_s) \in \{(1, B), (0, G)\}$) optimal wages are set according to the hard evidence so that $\hat{w}_{0G}^R \leq \hat{w}_{1B}^R$ if $\rho_v \leq \rho_y$ whereas the reverse is true for $\rho_v > \rho_y$.

In Corollary 1A in the appendix, we show that an increase in the precision of a signal leads to an increase (decrease) in wages whenever this signal brings good (bad) news about the level of effort of the agent. This implies that an increase in the precision of the output signal (supervision signal), raises the weight that is assigned to the hard (soft) signal in the optimal contract. In Corollary 2A in the appendix, we derive the relationship between wages under supervision and wages in the absence of supervision. We show that not supervising the agent yields an optimal contract $\hat{w}_N^R = (\hat{w}_{0\varnothing}^R, \hat{w}_{1\varnothing}^R)$ that satisfies $\hat{w}_{y\varnothing}^R \in (\hat{w}_{yB}^R, \hat{w}_{yG}^R)$ for $y \in \{0, 1\}$, and $\rho_v > \frac{1}{2}$. We establish the conditions under which the principal is willing to obtain an additional signal through supervision in Corollary 3A in the appendix. We also discuss how the decision to supervise the agent is affected by the precision of the hard and the soft signals. These preliminary results are in line with previous research such as Holmström (1979), Lambert (1985) and Banker and Datar (1989).

Our following result establishes a relationship between the cost of supervision and the precision of the signals. We show that an increase in the precision of the signals decreases the optimal expected wages to be paid by the principal in Stage 3 so that the cost of implementing the efficient level of effort decreases. We also analyze how the decision to supervise the agent is affected by the precision of the hard and the soft signals.

[17] This is the case because our signals satisfy the monotone likelihood ratio property.

Corollary 1 (Efficiency cost and precision of the signals)

i) As the precision of the hard or the soft signal increases the cost for the principal of achieving the efficient level of effort decreases.

ii) $\partial\frac{\hat{\mathbf{w}}_N^R\mathbf{P}_1^N-\hat{\mathbf{w}}^R\mathbf{P}_1}{\partial\rho_v} > 0.$

iii) $\partial\frac{\hat{\mathbf{w}}_N^R\mathbf{P}_1^N-\hat{\mathbf{w}}^R\mathbf{P}_1}{\partial\rho_y} < 0$

The interpretation of the first part of the corollary follows directly from the fact that both the hard and the soft signals are valuable. The last two parts of the corollary imply that supervision is less pervasive when the hard signal is more precise whereas the reverse is true when the soft signal is more precise.[18] This interpretation follows from the fact that $(\hat{\mathbf{w}}_N^R\mathbf{P}_1^N-\hat{\mathbf{w}}^R\mathbf{P}_1)$ measures the extent to which supervision lowers the expected cost for the principal of implementing the efficient level of effort. For a perfectly precise hard signal $\left(\rho_y = 1\right)$ the efficient level of effort can be implemented by the principal without supervising the agent since, in that case, she has complete information on the subordinate's level of effort.

4 Supervision and Influence

In this section we consider the case in which the supervisor can be influenced by the agent ($\pi > 0$). In that context, the principal may update the soft signal incorrectly as she suffers from cognitive biases in the perception of the supervision signal. If the principal decides to supervise the agent in this setup, she has two different options. On the one hand, the principal can propose influence contracts ($\mathbf{w}^I$) for which she anticipates that, in equilibrium, agents will be willing to manipulate the soft signal. On the other hand, the principal can deter manipulation attempts by proposing influence-free contracts ($\mathbf{w}^F$). In this latter case, the optimization problem of the principal includes an additional constraint to deter influence activities.[19] In what follows, we compare both strategies for the principal and characterize the properties that are satisfied by the optimal contracts that implement the efficient level of effort.

We solve our model by backward induction. We first determine the condition under which the agent undertakes the costly influence activity $(a = 1)$. Then, we analyze whether the principal is willing to deter influence activities from the agent and design influence-free contracts.

[18] This result is closely related to the classical trade-off between risk and incentives in the moral hazard literature. See Prendergast (1999) for a discussion of this trade-off in the light of the empirical literature.

[19] One of the important questions to be addressed in practice is whether the principal, being aware of her bias, should supervise the agent or not. We discuss this issue in Lemma 1A in the appendix, in which we specify the condition under which supervision will take place.

4.1 Influence contracts

If the principal decides to supervise the agent in an efficient equilibrium, she can allow for the influence activity by choosing an optimal contract $\hat{\mathbf{w}}^I = [\hat{w}^I_{1G}, \hat{w}^I_{1B}, \hat{w}^I_{0G}, \hat{w}^I_{0B}]$ that satisfies the condition that the agent will perform the influence activity ($a = 1$).[20] In that case, $\hat{\mathbf{w}}^I$ is defined as the wage vector that minimizes the cost of implementing the high level of effort ($\mathbf{w}^I \mathbf{P}^I_1$), where $\mathbf{P}^I_1$ is the probability vector associated with the case in which the agent exerts a high level of effort on the productive task and the principal accepts influence from the agent.

We show in Proposition 1A in the appendix that supervision remains valuable even in the presence of influence activities given that soft signals continue to be informative about the agent level of effort as long as $\rho_v > \frac{1}{2}$ and $\pi < 1$. We also characterize the optimal contract under influence. In line with Proposition 1, our results for the case of influence contracts indicate that optimal wages are non-decreasing in either the hard or the soft signal. It is also found that more weight is assigned to the hard signal when its precision (ρ_y) is higher than the precision of the soft signal (ρ_v). However, for $\rho_y < \rho_v$ it may not be the case that more weight is given to the soft signal since the principal being aware of her own biases (Assumption A), takes into account the possibility that the soft signal has been manipulated. In particular, we only observe that more weight is assigned to the soft signal if (i) its precision is sufficiently high $\left(\rho_y < \rho_v\right)$ and (ii) the principal's bias is sufficiently low ($\pi \leq \bar{\pi}(\rho_y, \rho_v)$ where $\bar{\pi}(\rho_y, \rho_v) := \frac{\rho_v - \rho_y}{\rho_v + \rho_y - 1}$).[21] If the latter condition is not satisfied, more weight is given to the hard signal compared to the soft signal even though $\rho_y < \rho_v$. It occurs because the precision of the soft signal is not high enough to compensate for the principal's bias.[22]

4.2 Influence-free contracts

Recall that there exists also the possibility for the principal to design influence-free contracts ($\mathbf{w}^F$) that discourage the agent from influencing his supervisor. We denote $\hat{\mathbf{w}}^F = (\hat{w}^F_{1B}, \hat{w}^F_{1G}, \hat{w}^F_{0G}, \hat{w}^F_{0B})$ the optimal

[20] We derive the condition (IA) under which the agent who is being supervised performs the influence activity in Lemma 1A in the appendix. We note that for costless influence activities ($\phi_a = 0$) the subset of optimal wages that satisfy the condition is non-empty. In general, there exists an upper bound for influence activities costs $\left(\phi_a \leq \bar{\phi}_a\right)$ for which the condition is satisfied.

[21] This threshold is determined by equating the likelihood ratios associated with the hard signal and the soft signal in the case of influence contracts. That is, $\frac{\rho_v + \pi(1-\rho_v)}{\pi\rho_v + (1-\rho_v)} = \frac{\rho_y}{1-\rho_y}$.

[22] When we compare the optimal contracts under influence $\hat{\mathbf{w}}^I$ and the optimal contract with rational supervision $\hat{\mathbf{w}}^R$ we conclude that the latter tends to put more weight on the hard signal relative to the soft signal. Further comparisons between these contracts are available in Corollary 4A in the appendix. This includes the proof that the efficiency cost incurred by the principal increases in the presence of influence ($\pi > 0$) with respect to the case of rational supervision whenever the soft signal becomes either more manipulable or more precise.

contract such that the agent is not willing to distort the supervisor's assessment on his work and denote $\mathbf{P}_1^F$ the probability vector associated with this contract.[23] It follows that the principal designs influence-free contracts to implement e_H as long as the expected wages that are paid by the principal under influence-free contracts are lower than in the case of influence contracts.

$$\hat{\mathbf{w}}^I \mathbf{P}_1^I \geq \hat{\mathbf{w}}^F \mathbf{P}_1 \tag{1}$$

If this condition is satisfied, the principal designs influence-free contracts by imposing an additional constraint in her optimization problem so as to discourage the influence activity. In Table 1 below we summarize the properties that are satisfied by the optimal contracts that implement the efficient level of effort both when the principal allows for influence ($\hat{\mathbf{w}}^I$) and when the principal designs influence-free contracts ($\hat{\mathbf{w}}^F$) that deter influence activities (see Proposition 2A in the appendix for further details).

Table 1. Characterization of the optimal contracts that implement e_H

	INFLUENCE $\mathbf{w}^j = \mathbf{w}^I$	INFLUENCE-FREE $\mathbf{w}^j = \mathbf{w}^F$
A. Impact of the principal's bias (π) on the weight that is assigned to the signals		
$\frac{\partial \hat{w}_{1G}^j}{\partial \pi}$	Negative	Negative
$\frac{\partial \hat{w}_{1B}^j}{\partial \pi}$	Zero	Positive
$\frac{\partial \hat{w}_{0G}^j}{\partial \pi}$	Negative	Negative
$\frac{\partial \hat{w}_{0B}^j}{\partial \pi}$	Zero	Positive
B. Relative weight assigned to the hard signal in the optimal contract		
$\frac{\partial}{\partial \pi}(\hat{w}_{1B}^j - \hat{w}_{0G}^j)$	Positive	Positive
C. Wage compression and the power of incentives		
$\frac{\partial}{\partial \pi}(\hat{w}_{yG}^j - \hat{w}_{yB}^j)$	The power of incentives decreases in the soft signal (v_s) with respect to the principal's bias (π)	

Our results summarized in Table 1 indicate that the optimal contract that implements the efficient equilibrium $\hat{\mathbf{w}}^j$ for $j \in \{I, F\}$ is such that an increase in the principal's bias (π) raises the weight which is

[23] By definition we know that $\mathbf{P}_1^F := \mathbf{P}_1$.

assigned to the hard signal. This occurs because an increase in the principal's bias reduces the likelihood ratio associated with the soft signal, implying that conditionally on observing a positive soft signal $v_s = G$, it is less likely that the agent has exerted a high level of effort.[24] Importantly, the influence and the influence-free contracts differ with respect to the likelihood ratio associated with a negative soft signal $v_s = B$. This is the case because optimal wages $\hat{w}^I_{0B}$ and $\hat{w}^I_{1B}$ are not affected by the principal's bias whereas $\hat{w}^F_{0B}$ and $\hat{w}^F_{1B}$ increase in π. Indeed, as π increases, the soft signal becomes more manipulable and influence activities become more appealing. In order to offset this effect of an increase in π, influence-free contracts specify larger payments upon reception of a negative soft signal so as to deter agents from engaging in influence activities and distorting negative soft signals.

The previous results imply that the variance of wages decreases in the bias of the principal wether influence or influence-free contracts are implemented (i.e., the power of incentives decreases in the soft signal v_s with respect to the principal's bias π). In our model, the principal is willing to use the hard signal more intensively relative to the soft signal as π increases since the level of information of the soft signal decreases in the principal's bias.[25] It can be shown that the manipulability of the soft signal tends to increase the cost for the principal of implementing the efficient level of effort (see Proposition 3A in the appendix). That is, as the soft signal becomes more manipulable, supervision tends to be less effective as a disciplining device for the agent because the accuracy of this signal decreases in π. This implies that a larger rent will have to be paid to the risk-averse agent in order to ensure that the participation constraint holds. As a result, the principal would be better-off in an organizational environment in which agents do not have the possibility to influence her assessments. For example, supervisors may limit communication with subordinates to avoid influence activities (Milgrom, 1988; Milgrom and Roberts, 1988). They may also design an organizational structure that limits interpersonal relationships between employees at different levels of the hierarchy. This can be achieved by having employees at different layers of the hierarchy work at different locations as is the case in the increasingly popular virtual organizations. In that case, employees' supervision is performed through computer-mediated communication systems.[26] However, the quality of the supervision signal may be undermined in those cases (Jarvenpaa and Leidner, 1999). The optimal strategy consists for the principal of finding the right balance between getting access to information about the agent's level of effort while

[24] Indeed, this likelihood ratio is equal to $1 - \frac{1-\rho_v+\pi\rho_v}{\rho_v}$.

[25] To see empirical evidence on the prevalence of hard information, see Liberti and Mian (2009), who highlight that higher hierarchical distance between the decision-maker and the agent who collects the information yields less reliance on soft information.

[26] A large number of programs such as Spectorsoft, Virtual Monitoring^{TM}, Employee Monitoring or Webwatcher are already available to monitor employees' activities. An early account of computer-based monitoring systems was considered in Chalykoff and Kochan (1989).

avoiding influence activities.

5 Influence Costs and the Value of the Firm

Influence activities are costly for the organization as they detract workers from their productive task (Milgrom and Roberts, 1992). In this section we consider the case in which the influence activity ($a \in \{0,1\}$) affects the value of the firm negatively. We assume that influence activities are time-consuming and undermine the quality of the work of the agent. This *productivity-based* influence cost translates into the following assumption in which influence activities reduce the probability that the agent obtains the high level of output for a given level of effort.

Assumption C (Influence costs and the value of the firm)

If the agent decides to undertake an influence activity ($a = 1$), then $P\left[y=1 \mid e=e_H\right] = (1-\alpha)\,\rho_y$ and $P\left[y=1 \mid e=e_L\right] = (1-\alpha)\left(1-\rho_y\right)$ where $\alpha \in [0,1]$ measures the influence cost.

We assume no *privately-incurred* influence costs, that is $\phi_a = 0$.

Assumption C states that undertaking the influence activity is costly for the principal as it undermines the productivity of the agent. Thus, the influence activity decreases the likelihood for the principal of receiving the high level of output ($y = 1$) and therefore reduces her expected revenues.

We start by considering the case in which the principal decides to supervise the agent in Stage 1. We analyze the decision of the principal to supervise the agent or not in Section 5.3.

In line with the previous section, the principal will either design contracts that allow for influence activities in equilibrium (influence contracts) or design contracts that deter influence activities (influence-free contracts).

5.1 Influence contracts

In the next proposition we characterize the optimal influence contract $\hat{\mathbf{w}}^{\iota} = (\hat{w}^{\iota}_{1G}, \hat{w}^{\iota}_{1B}, \hat{w}^{\iota}_{0G}, \hat{w}^{\iota}_{0B})$ that implements the efficient level of effort e_H in the case of *productivity-based* influence costs.

Proposition 2 (Influence contracts and power of incentives)

i) The optimal influence contract that implements the efficient equilibrium satisfies either the condition that an increase in the principal's bias (π) *or that a decrease in influence costs* (α) *raises the weight that is assigned to the hard signal in the optimal contract.*

ii) The optimal influence contract that implements the efficient equilibrium satisfies the condition that the power of incentives decreases in the soft signal (v_s) with respect to the principal's bias (π) whereas the power of incentives decreases in the hard signal with respect to influence costs (α).

As in the case of private influence costs (see Table 1, right column), we find that an increase in the manipulability of the soft signal (π) reduces its accuracy and leads the principal to put more weight on the hard signal. In addition, the power of incentives decreases in the soft signal with respect to the manipulability of the signal. Consequently, the manipulability of the soft signal tends to increase the cost for the principal of implementing the efficient level of effort.[27]

The novel part of Proposition 2 is related to the comparative statics of the *productivity-based* influence costs (α). In particular, a reduction in these costs tends to lower the weight that is assigned to the hard and non-manipulable signal (y). This is the case because the accuracy of a low level of output ($y = 0$) as a predictor of the level of effort of the agent decreases as α rises. Indeed, in the presence of *productivity-based* influence costs, a low level of production can be attributed either to a low level of effort or to influence activities. This implies that a low output signal is interpreted less negatively in the presence of *productivity-based* influence costs, that is $\frac{\partial \hat{w}^{\iota}_{0v_s}}{\partial \alpha} > 0$ for any $v_s \in \{B, G\}$.[28] In the extreme case in which influence costs destroy the whole output ($\alpha = 1$) the signal $y = 0$ is uninformative about the level of effort of the agent. As a result, the weight of the hard signal in the agent's wage will be reduced as *productivity-based* influence costs increase. Also, applying Definition 3 we know that the power of incentives decreases in the hard signal with respect to α since $\frac{\partial \hat{w}^{\iota}_{0v_s}}{\partial \alpha} > 0$ and $\frac{\partial \hat{w}^{\iota}_{1v_s}}{\partial \alpha} = 0$ for any $v_s \in \{B, G\}$.

5.2 Influence-free contracts

Recall that the principal needs not accept influence activities from the agent and may design influence-free contracts that deter manipulation attempts. We denote by $\hat{\mathbf{w}}^f = (\hat{w}^f_{1G}, \hat{w}^f_{1B}, \hat{w}^f_{0G}, \hat{w}^f_{0B})$ $\left[\mathbf{P}^f_1\right]$ the optimal influence-free wage contract [probability vector] in the case of *productivity-based* influence costs.[29] The principal designs influence-free contracts instead of influence contracts in Stage 1 as long as the following condition is satisfied:

$$\alpha R(y) + \mathbf{w}^{\iota} \mathbf{P}^{\iota}_1 \geq \mathbf{w}^f \mathbf{P}_1 \tag{2}$$

This condition states that it is optimal for the principal to design influence-free contracts as long as the cost of implementing an efficient equilibrium under influence-free contracts is lower than in the case of

[27] The proof is similar to the case of private influence costs (see Proposition 3A in the appendix).

[28] Note that the informativeness of the hard signal $y = 1$ is not affected by α, that is $\frac{\partial \hat{w}^{\iota}_{1v_s}}{\partial \alpha} = 0$ for any $v_s \in \{B, G\}$.

[29] As we pointed out in Section 4.2, we know that $\mathbf{P}^f_1 := \mathbf{P}_1$

influence contract. The cost associated with the use of influence contracts consists of two parts: the reduction in the revenues of the firm due to destructive influence activities ($\alpha R(y)$) and the payment of wages to the agent ($\mathbf{w}^{\iota}\mathbf{P}_1^{\iota}$). It is worth noting that the term $\alpha R(y)$ corresponds to *productivity-based* influence costs that do not enter the principal's decision when influence costs are privately incurred by the agent (see condition (1)). We determine in the next proposition two sufficient conditions for the principal to choose influence-free contracts in the presence of *productivity-based* costs.

Proposition 3 (Influence-free strategy)

i) If the influence costs (α) satisfies the condition that $\alpha \geq \alpha_f$ then the principal will use influence-free contracts to implement the efficient equilibrium.

ii) If the revenues of the high level of output $R(1)$ satisfies the condition that $R(1) \geq R_f$ then the principal will use influence-free contracts to implement the efficient equilibrium.

The first part of the proposition states that the principal is better-off eliminating influence activities by setting influence-free contracts when the cost of influence activities for the firm is large ($\alpha \geq \alpha_f$). In the extreme case in which $\alpha = 1$ the presence of influence activities will bring the revenues of the principal down to $R(0)$ meaning that influence-free contracts cannot be dominated by influence contracts. This is the case because influence contracts would generate the minimum possible expected revenues for the principal. Indeed, in the worst scenario the principal can always eliminate influence activities by setting wages that are not contingent on the soft signal ($\hat{w}^f_{yB} = \hat{w}^f_{yG}$ for $y \in \{0,1\}$) in which case the agent may still have incentives to exert a high level of effort if the hard signal is sufficiently informative.

The second part of the proposition relies on the fact that the cost for the firm associated with influence activities increases in $R(y)$. Indeed, the more productive the agent is, the more detrimental influence activities are to the value of the firm. As a result, the principal will design influence-free contracts whenever the high level of output produced by the agent is sufficiently valuable to the principal, that is for $R(1) \geq R_f$.

In the following proposition we characterize the main properties of the optimal influence-free contract $\hat{\mathbf{w}}^f$. We denote $\bar{\alpha} = \max\{\alpha_0, \alpha_1, \alpha_f\}$ where $\alpha_0 = \frac{\pi(1-\rho_y)}{(1-\pi)\rho_y}$ and $\alpha_1 = \frac{\pi(1-\rho_v)}{(1-\pi)\rho_v+\pi}$.

Proposition 4 (Influence-free contracts and power of incentives) *i) The optimal influence-free contract that implements the efficient level of effort satisfies the condition that either an increase in the principal's bias (π) or an increase in productivity-based influence costs (α) raises the weight that is assigned to the hard signal.*

ii) The optimal influence-free contract that implements the efficient level of effort satisfies the condition that the power of incentives decreases in the soft signal (v_s) with respect to the principal's bias (π). In *addition, for any $\alpha \geq \bar{\alpha}$, the power of incentives increases in the hard signal with respect to influence costs* (α)*. As a result, the variance of wages increases in productivity-based influence costs* (α)*.*

Similarly to the case of influence contracts, influence-free contracts are such that the weight assigned to soft manipulable signals increase as the manipulability of the signal increases (π). This finding holds for influence and influence-free contracts whether we consider *productivity-based* or *privately-incurred* influence costs (see Table 1). Nonetheless, in the presence of *productivity-based* influence costs, influence and influence-free contracts differ since an increase in influence costs (α) raises the weight that is assigned to the hard signal in the case of influence-free contract (Proposition 4i)) while the opposite is true in the case of influence contracts (Proposition 2i)).

The intuition for this result follows from the fact that principals can use one of the following two mechanisms in order to design influence-free contracts and deter influence activities. The first approach is to set up incentive contracts that are less responsive to the soft signal so as to reduce the expected benefits associated with influence activities. This first approach would induce even greater wage compression and weaker incentives in the case of *productivity-based* influence costs than in the case of private influence costs. This is the case because the cost of initiating influence activities is lower when it is not privately incurred by the agent making the manipulation of soft signals potentially more appealing to him. As a result, deterring influence activities in the presence of *productivity-based* influence costs will require a high level of wage compression and low-powered incentives. An alternative approach, which is actually followed by the principal in equilibrium, consists of increasing the opportunity cost of influence activities by increasing the incentives associated with the hard signal. In that case, influence activities become less profitable as they reduce the probability that the agent will get the high payment associated with a high level of performance on the hard signal. Consequently, the principal will increase the weight given to the hard signal so as to discourage influence activities (see Proposition 2i).

The second part of Proposition 2 follows from the fact that for any $\alpha \geq \bar{\alpha}$ the following comparative statics hold $\frac{\partial \hat{w}^f_{1G}}{\partial \alpha} > 0$, $\frac{\partial \hat{w}^f_{1B}}{\partial \alpha} > 0$, $\frac{\partial \hat{w}^f_{0G}}{\partial \alpha} < 0$ and $\frac{\partial \hat{w}^f_{0B}}{\partial \alpha} < 0$. Applying Definition 3, we conclude that, for any $\alpha \geq \bar{\alpha}$, the power of incentives increases in the hard signal with respect to α. Notice that the threshold ($\bar{\alpha}$) above which influence costs lead to an increase in the power of incentives increases in the principal's bias (π). This occurs because for high values of π we obtain that $\frac{\partial \hat{w}^f_{1G}}{\partial \alpha} \leq 0$ in which case the power of incentives does not increase in the hard signal with regard to influence costs. For large values of π the principal's mind is more manipulable and influence activities are more appealing to agents. As a result, eliminating influence activities may require decreasing the pay associated with the highly manipulable soft signal ($\frac{\partial \hat{w}^f_{yG}}{\partial \alpha} < 0$ for any $y \in \{0, 1\}$) in addition to increasing the pay associated with a high level of output ($\frac{\partial \hat{w}^f_{1v_s}}{\partial \alpha} > 0$ for any

$v_s \in \{B, G\}$). If the former effect dominates the latter then $\frac{\partial \hat{w}^f_{1G}}{\partial \alpha} \leq 0$.

The main implication of Proposition 4 is that influence-free contracts may significantly differ from influence contracts with regard to the weight given to hard and soft signals. This finding suggests that in the presence of *productivity-based* influence costs workers with different levels of productivity may be offered different types of contracts. We elaborate on this conjecture in the next corollary by showing that high-powered incentives and influence-free contracts are more likely to be offered to agents for which influence is especially costly in terms of firm productivity.[30]

Corollary 2 (Influence-free contract and agent's productivity) *If the productivity-based influence costs α satisfies the condition that $\alpha \geq \bar{\alpha}$, then there exists a level of productivity $\bar{R}(\alpha)$ above which wages offered to low-productivity agents $\left(R(1) < \bar{R}(\alpha)\right)$ are less responsive to the hard signal than they are for high-productivity agents $\left(R(1) \geq \bar{R}(\alpha)\right)$.*

This corollary follows from Proposition 3 according to which high-productivity workers ($R(1) \geq R_f$) will be offered influence-free contracts whereas low-productivity agents ($R(1) < R_f$) will be offered contracts under which it is optimal for the agents to influence the principal's perception of the soft signal. This result is in line with the main findings in Green (1998) that studies the impact of skills on wages. Green (1998) finds that computer skills (i.e., hard signals) are highly valued whereas communication skills (i.e., soft signals) have little impact on wages, so that workers at higher levels of the hierarchy receive wages that are more responsive to the hard signal than to the soft signal.

More generally, our findings suggest that top executives, in particular CEOs, are more likely to be paid according to hard signals than employees at lower levels of the hierarchy. For example, our results are consistent with the widespread use of stock options in top executives' compensation packages in addition to bonus pay (see Tirole, 2006 pp.21-25 for a review). Indeed, bonus plans are typically based on accounting data that can be manipulated by top executives while stock options incentives are less likely to be affected by such manipulation attempts. As a result, the use of stock options in top executives' compensation packages can be motivated by the willingness to limit the influence activities that are inherent to bonus incentives plans. Influence activities may then account for the widespread use of stock options despite the loose link that exists between top executives' levels of effort and stock prices.

[30] $\bar{R}(\alpha)$ denotes the level of productivity such that the principal is indifferent between supervising the agent or not for a given level of influence costs α.

5.3 Supervision

In this section, we analyze whether it is optimal for the principal to supervise the agent and gather a manipulable signal in a context of *productivity-based* influence costs. In the following corollary we show that, even in the absence of supervision costs ($\phi_s = 0$), the principal may decide to avoid supervision and rely solely on the hard signal when the influence activity entails a cost for the organization.

Corollary 3 (Supervision and influence) *If the principal's bias π satisfies that $\pi \geq \pi^-$ then the principal will not be willing to supervise the agent, even though supervision is costless.*

The intuition behind this result follows from the fact that supervision generates an indirect cost by permitting the emergence of influence activities that are detrimental to the firm. This implies that technologically costless supervision can actually destroy firm value. This result holds for $\pi \geq \pi^-$ because discouraging influence activities is very costly for large values of π. Indeed, if the soft signal is highly manipulable the principal will have to dissuade influence activities by putting a particularly important weight on the hard signal that may increase the variance of wages and the cost of implementing the efficient level of effort as a result. For example, in the extreme case in which $\pi = 1$ and $\alpha = 0$ the principal will be indifferent between supervising and not supervising the agent since then $\hat{\mathbf{w}}^\iota P_1^\iota = \hat{\mathbf{w}}_N^R P_1^N$. However, if we take $\pi = 1$ and $\alpha = \varepsilon$ where $\varepsilon > 0$ and ε is arbitrarily close to zero, the principal will not be willing to supervise the agent so as to avoid influence activities that undermine the productivity of the agents. In that case, $\varepsilon R(1) + \hat{\mathbf{w}}^\iota P_1^\iota \geq \hat{\mathbf{w}}_N^R P_1^N$ so that the principal will save costs of implementing the efficient level of effort by focusing on the hard signal and not supervising the agent.[31]

Interestingly, this result differs from the case of private influence costs in which supervision was always valuable for the principal as long as $\rho_v > \frac{1}{2}$ and $\pi < 1$. This difference follows from the fact that under *productivity-based* influence costs the principal faces a trade-off between gathering an informative soft signal and incurring influence costs associated with the supervision activity. Our result offers an alternative explanation to the fact that supervision activities may lower effort and motivation of employees (Frey, 1993, Falk and Kosfeld, 2006). The previous authors stress that agents tend to lower their level of effort as a response to the signal of distrust created by the principal's decision to supervise their subordinate. In our setting, supervision undermines the provision of effort because it gives the agent the opportunity to engage in destructive influence activities.

[31] A similar reasoning can be applied to the case in which influence-free contracts are used, that is $\alpha \geq \alpha_f$. In that context, the cost of implementing the efficient level of effort follows from the fact that the principal will have to dissuade influence activities by putting an excessive weight on the hard signal that may increase the variance of wages and increase the cost of implementing the efficient equilibrium compared with the case without supervision.

6 Conclusion

In this paper, we analyzed the design of incentive contracts in a principal-agent model in which the agent had the possibility to manipulate pieces of information about his actual performance by undertaking influence activities. We considered successively the cases in which influence activities entailed a private cost to the agent and the case in which those activities diverted the agent from producing for the principal.

In both contexts, we found that an increase in the manipulability (i.e., softness) of the signal increases information asymmetry between the agent and the principal and increases the cost of implementing the efficient level of effort as a result. Also, we showed that an increase in the manipulability of the soft signal raises the weight assigned to the non-manipulable hard signal and decreases the power of incentives associated with the soft signal whether the principal designs influence or influence-free contracts.

In the case of *productivity-based* influence costs we identified fundamental differences between influence and influence-free contracts regarding the effect of an increase in influence costs. In particular, the weight assigned to the hard signal decreases in the influence costs in the case of influence contracts while the opposite is true in the case of influence-free contracts. This result holds because in the case of *productivity-based* influence costs, it is optimal for the principal to deter influence activities by increasing their opportunity cost. This is achieved by raising the incentives associated with the hard signal. More specifically, we show that high-powered incentives and influence-free contracts are more likely to be assigned to agents for which influence is especially costly in terms of firm productivity. This result is in line with empirical findings in Green (1998) showing that workers at higher levels of the hierarchy receive wages that are more responsive to the computer-based hard signal than to the communication-based soft signal (see also Liberti and Mian 2009). In addition, our findings suggest that the widespread use of stock options in top executives' compensation packages may be attributed to the low manipulability of stock prices compared with accounting data on the basis of which bonus incentives are calculated.

Finally, we showed that in the presence of *productivity-based* influence costs the principal may intentionally avoid supervising the agent when the manipulability of the soft signal is high. This result holds even if supervision is costless since the principal faces a trade-off between gathering an informative soft signal and incurring influence costs associated with the supervision activity.

Although our model provides a generalization of the principal-agent model for the case in which some signals are manipulable, we deliberately abstract away from the interesting case of multi-agents frameworks. However, in their definition of influence activities, Milgrom and Roberts (1992) envisage not only personal attempts to manipulate the principal's view of oneself but also the time devoted by organizational members to countervail the manipulation attempts of their coworkers. In order to apprehend influence activities at the organizational level, extending our analysis to the case of multi-agent models with team production and hierarchies may be a fruitful area for future research.

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7 Appendix

Proof of Proposition 1.

We denote $\mathbf{w} = [w_{1G}, w_{1B}, w_{0G}, w_{0B}]$ the contingent contract offered by the principal in the case of supervision. We denote $\mathbf{P}_1$ $[\mathbf{P}_0]$ the probability of receiving each of these payments when exerting a high [low] level of effort, that is:

$$\mathbf{P}_1 := (p_{i1})_{i\in\{1,\ldots,4\}} = \begin{bmatrix} \rho_y\rho_v \\ \rho_y(1-\rho_v) \\ (1-\rho_y)\rho_v \\ (1-\rho_y)(1-\rho_v) \end{bmatrix}$$

And $$\mathbf{P}_0 := (p_{i0})_{i\in\{1,\ldots,4\}} = \begin{bmatrix} (1-\rho_y)(1-\rho_v) \\ (1-\rho_y)\rho_v \\ \rho_y(1-\rho_v) \\ \rho_y\rho_v \end{bmatrix}.$$

The optimal contract that implements the efficient equilibrium in the case of rational supervision solves the following problem:

$$\begin{cases} (1)\ \ \hat{\mathbf{w}}^R = \min\limits_{\mathbf{w}\in\mathbb{R}^4} \mathbf{w}\mathbf{P}_1 \\ \quad (2)\ \ \mathbf{u}(\mathbf{w})\,\mathbf{P}_1 - \phi_e \geq \bar{u} \qquad\qquad \textbf{IR} \\ \quad (3)\ \ \mathbf{u}(\mathbf{w})\,\mathbf{P}_1 - \phi_e \geq \mathbf{u}(\mathbf{w})^\top\,\mathbf{P}_0 \qquad \textbf{IC} \end{cases}$$

where $\mathbf{u}(\mathbf{w})$=$[u(w_{1G}), u(w_{1B}), u(w_{0G}), u(w_{0B})]$. In order to ensure that the optimization program is concave we will write the optimization program as a function of $h = u^{-1}$ the inverse function of $u(\cdot)$, which is increasing and convex, that is $h' > 0$ and $h'' > 0$.[32] We then define $u_{1G} = u(w_{1G}), u_{1B} = u(w_{1B}), u_{0G} = u(w_{0G})$ and $u_{0B} = u(w_{0B})$ so that $w_{1G} = h(u_{1G})$, $w_{1,B} = h(u_{1B}), w_{0G} = h(u_{0G})$ and $w_{0B} = h(u_{0B})$. Thereby, the Principal solves:

$$\begin{cases} (1)\ \ \hat{\mathbf{w}}^R = \min\limits_{\{(u_{0v},u_{1v})\}} p_{11}h(u_{1G}) + p_{21}h(u_{1B}) + p_{31}h(u_{0G}) + p_{41}h(u_{0B}) \\ \quad (2)\ \ p_{11}u_{1G} + p_{21}u_{1B} + p_{31}u_{0G} + p_{41}u_{0B} - \phi_e \geq \bar{u} \qquad\qquad \textbf{IR} \\ \quad (3)\ \ (p_{11}-p_{10})u_{1G} + (p_{21}-p_{20})u_{1B} + (p_{31}-p_{30})u_{0G} \qquad \textbf{IC} \\ \qquad\qquad +(p_{14}-p_{04})u_{0B} - \phi_e \geq 0 \end{cases}$$

We denote $\lambda \geq 0$ and $\mu \geq 0$ the Lagrange multipliers associated with the incentive constraint and the individual rationality constraint. We then get the following first order conditions.

[32] We use this change of variable $h = u^{-1}$ following Jean-Jaques Laffont and David Martimort (2002).

$$\begin{cases} (1_{0B}) \ h'(u_{1G}) = \frac{\lambda p_{11}+\mu(p_{11}-p_{10})}{p_{11}} \\ (1_{0G}) \ h'(u_{1B}) = \frac{\lambda p_{21}+\mu(p_{21}-p_{20})}{p_{21}} \\ (1_{1B}) \ h'(u_{0G}) = \frac{\lambda p_{31}+\mu(p_{31}-p_{30})}{p_{31}} \\ (1_{1G}) \ h'(u_{0B}) = \frac{\lambda p_{41}+\mu(p_{41}-p_{40})}{p_{41}} \end{cases}$$

Since $h^{'}(x) = 1/u'(x)$ we can write:

$$\begin{cases} (1_{1G}) \ u'\left(\hat{w}_{1G}^{R}\right) = \frac{\rho_y \rho_v}{\lambda \rho_y \rho_v + \mu(\rho_y+\rho_v-1)} \\ (1_{1B}) \ u'\left(\hat{w}_{1B}^{R}\right) = \frac{(1-\rho_v)\rho_y}{\lambda(1-\rho_v)\rho_y+\mu\left(\rho_y-\rho_v\right)} \\ (1_{0G}) \ u'\left(\hat{w}_{0G}^{R}\right) = \frac{\left(1-\rho_y\right)\rho_v}{\lambda\left(1-\rho_y\right)\rho_v+\mu\left(\rho_v-\rho_y\right)} \\ (1_{0B}) \ u'\left(\hat{w}_{0B}^{R}\right) = \frac{\left(1-\rho_y\right)(1-\rho_v)}{\lambda\left(1-\rho_y\right)(1-\rho_v)+\mu(1-\rho_y-\rho_v)} \end{cases}$$

In addition, we get the feasibility and Slackness conditions:

(2_{IR}) $\mathbf{u}\left(\hat{\mathbf{w}}^{R}\right)\mathbf{P}_1 - \phi_e - \bar{u} \geq 0$

(3_{IC}) $\mathbf{u}\left(\hat{\mathbf{w}}^{R}\right)(\mathbf{P}_1 - \mathbf{P}_0) - \phi_e \geq 0$

(4_{λ}) $\lambda[\mathbf{u}\left(\hat{\mathbf{w}}^{R}\right)\mathbf{P}_1 - \phi_e - \bar{u}] = 0$

(5_{μ}) $\mu[\mathbf{u}\left(\hat{\mathbf{w}}^{R}\right)(\mathbf{P}_1 - \mathbf{P}_0) - \phi_e)] = 0$

CASE 1. It should be clear that $\lambda = \mu = 0$ is not a solution for the problem above because it would imply $u'(\hat{w}) = \infty$.

CASE 2. If $\mu > 0$ and $\lambda = 0$ then,

$$\left\{ (1_{0B}) \quad u'\left(\hat{w}_{0B}^{R}\right) = \frac{\left(1-\rho_y\right)(1-\rho_v)}{\mu(1-\rho_y-\rho_v)} > 0 \text{ iff } \rho_y + \rho_v < 1 \right.$$

But $\rho_y + \rho_v < 1$ contradicts $\rho_y, \rho_v \in [\frac{1}{2}, 1]$

CASE 3. If $\mu = 0$ and $\lambda > 0$ then,

$$\left\{ u'\left(\hat{w}_{0B}^{R}\right) = u'\left(\hat{w}_{0G}^{R}\right) = u'\left(\hat{w}_{1B}^{R}\right) = u'\left(\hat{w}_{1G}^{R}\right) = \frac{1}{\lambda} > 0 \right.$$

In this case, the Principal's optimal choice is to propose a fixed wage contract but the agent will not perform high effort because (3_{IC}) does not hold.

CASE 4. Therefore for the solution to exist, $\mu > 0$ and $\lambda > 0$ so (**IC**) and (**IR**) are binding constraints.[33]

Thus,

$$\begin{cases} (1_{0B}) \quad u'\left(\hat{w}_{0B}^{R}\right) = \frac{\left(1-\rho_y\right)(1-\rho_v)}{\lambda\left(1-\rho_y\right)(1-\rho_v)+\mu(1-\rho_y-\rho_v)} \\ (1_{0G}) \quad u'\left(\hat{w}_{0G}^{R}\right) = \frac{\left(1-\rho_y\right)\rho_v}{\lambda\left(1-\rho_y\right)\rho_v+\mu\left(\rho_v-\rho_y\right)} \\ (1_{1B}) \quad u'\left(\hat{w}_{1B}^{R}\right) = \frac{(1-\rho_v)\rho_y}{\lambda(1-\rho_v)\rho_y+\mu\left(\rho_y-\rho_v\right)} \\ (1_{1G}) \quad u'\left(\hat{w}_{1G}^{R}\right) = \frac{\rho_y \rho_v}{\lambda \rho_y \rho_v + \mu(\rho_y+\rho_v-1)} > 0 \\ (2_{IR}) \ \mathbf{u}\left(\hat{\mathbf{w}}^{R}\right)\mathbf{P}_1 - \phi_e - \bar{u} = 0 \\ (3_{IC}) \ \mathbf{u}\left(\hat{\mathbf{w}}^{R}\right)(\mathbf{P}_1 - \mathbf{P}_0) - \phi_e = 0 \end{cases}$$

[33] MacLeod (2003) and Holmström (1979) find exactly the same result. Hereafter, we focus on the case of $\mu > 0$ and $\lambda > 0$.

In order to ensure that $u'(\cdot) > 0$ we would need the denominator being positive. For this to be satisfied, we need to know the relationship between the precision of the signals. For instance, when $\rho_y > \rho_v$ we would need $\frac{\mu}{\lambda} < \max\left\{\frac{\rho_v}{(\rho_y-\rho_v)}, \frac{1-\rho_v}{(\rho_y+\rho_v-1)}\right\} = \frac{\rho_v}{(\rho_y-\rho_v)}$ so that $u'\left(\hat{w}_{0B}^R\right)$ and $u'\left(\hat{w}_{0G}^R\right)$ are both positive.

Besides,

$$\begin{cases} u'\left(\hat{w}_{0G}^R\right) \geq u'\left(\hat{w}_{1B}^R\right) \text{ for } \rho_y \geq \rho_v \Leftrightarrow \hat{w}_{0G}^R \leq \hat{w}_{1B}^R \text{ for } \rho_y \geq \rho_v \\ \text{Then, for } \rho_y \geq \rho_v\text{: } u'\left(\hat{w}_{1G}^R\right) < u'\left(\hat{w}_{1B}^R\right) \leq u'\left(\hat{w}_{0G}^R\right) < u'\left(\hat{w}_{0B}^R\right) \quad \blacksquare \\ \Leftrightarrow \hat{w}_{0B}^R < \hat{w}_{0G}^R \leq \hat{w}_{1B}^R < \hat{w}_{1G}^R \end{cases}$$

Proof of Corollary 1A. If we use the Implicit Function Theorem in equations (1_{0B}), (1_{0G}), (1_{1B}) and (1_{1G}) above, we get that:

$$\begin{cases} \frac{\partial \hat{w}_{0B}^R}{\partial \rho_v} = -\frac{\mu\rho_y(\rho_y-1)}{u''\left(\hat{w}_{0B}^R\right)(\lambda\left(\rho_y-1\right)(\rho_v-1)+\mu(1-\rho_y-\rho_v))^2} < 0 \\ \frac{\partial \hat{w}_{0G}^R}{\partial \rho_v} = \frac{\mu\rho_y(\rho_y-1)}{u''\left(\hat{w}_{0G}^R\right)(\lambda\left(\rho_y-1\right)\rho_v+\mu\left(\rho_y-\rho_v\right))^2} > 0 \\ \frac{\partial \hat{w}_{1B}^R}{\partial \rho_v} = -\frac{\mu\rho_y(\rho_y-1)}{u''\left(\hat{w}_{1B}^R\right)(\lambda(\rho_v-1)\rho_y+\mu\left(\rho_v-\rho_y\right))^2} < 0 \\ \frac{\partial \hat{w}_{1G}^R}{\partial \rho_v} = \frac{\mu\rho_y(\rho_y-1)}{u''\left(\hat{w}_{1G}^R\right)(\lambda\rho_y\rho_v+\mu(\rho_y+\rho_v-1))^2} > 0 \end{cases}$$

Similarly,

$$\begin{cases} \frac{\partial \hat{w}_{0B}^R}{\partial \rho_y} = -\frac{\mu\rho_v(\rho_v-1)}{u''\left(w_{0B}^R\right)(\lambda\left(\rho_y-1\right)(\rho_v-1)+\mu(1-\rho_y-\rho_v))^2} < 0 \\ \frac{\partial \hat{w}_{0G}^R}{\partial \rho_y} = \frac{\mu\rho_v(\rho_v-1)}{u''\left(w_{0G}^R\right)(\lambda\left(\rho_y-1\right)\rho_v+\mu\left(\rho_y-\rho_v\right))^2} < 0 \\ \frac{\partial \hat{w}_{1B}^R}{\partial \rho_y} = \frac{\mu\rho_v(\rho_v-1)}{u''\left(w_{1B}^R\right)(\lambda(\rho_v-1)\rho_y+\mu\left(\rho_v-\rho_y\right))^2} > 0 \\ \frac{\partial \hat{w}_{1G}^R}{\partial \rho_y} = \frac{\mu\rho_v(\rho_v-1)}{u''\left(w_{1G}^R\right)(\lambda\rho_y\rho_v+\mu(\rho_y+\rho_v-1))^2} > 0 \end{cases}$$

Therefore,

$$\left\{ \frac{\partial \hat{w}_{0B}^R}{\partial \rho_v} < 0, \frac{\partial \hat{w}_{0G}^R}{\partial \rho_v} > 0, \frac{\partial \hat{w}_{1B}^R}{\partial \rho_v} < 0, \frac{\partial \hat{w}_{1G}^R}{\partial \rho_v} > 0 \right.$$

$$\left\{ \frac{\partial \hat{w}_{0B}^R}{\partial \rho_y} < 0, \frac{\partial \hat{w}_{1B}^R}{\partial \rho_y} < 0, \frac{\partial \hat{w}_{1G}^R}{\partial \rho_y} > 0, \frac{\partial \hat{w}_{0G}^R}{\partial \rho_y} > 0 \right.$$

So that an increase in the precision of the output signal (supervision signal), raises the weight that is assigned to the hard (soft) signal in the optimal contract when supervision takes place. $\blacksquare$

Proof of Corollary 2A. When the Principal does not supervise ($v = \oslash$), this can be interpreted as a special case of the derivations above where $\rho_v = \frac{1}{2}$. In that case, the contingent contract offered by the principal $\left(\mathbf{w}^R\right)$ to the agent is defined by two contingent payments that are respectively denoted: $w_{1\varnothing}^R$ and $w_{0\varnothing}^R$. Another way to consider the case $v = \{\varnothing\}$ is to repeat the analysis in Proposition 1 with $\rho_v = \frac{1}{2}$.

In both cases, we obtain the following optimal contract.

$$(1_L) \quad u'\left(\hat{w}_{0G}^R\right) = u'\left(\hat{w}_{0B}^R\right) = \frac{\frac{1}{2}\left(1-\rho_y\right)}{\frac{1}{2}\lambda\left(1-\rho_y\right)+\mu(\frac{1}{2}-\rho_y)} = u'\left(\hat{w}_{0\varnothing}^R\right)$$

$$(1_H) \quad u'\left(\hat{w}_{1G}^R\right) = u'\left(\hat{w}_{1B}^R\right) = \frac{\frac{1}{2}\rho_y}{\frac{1}{2}\lambda\rho_y+\mu(\rho_y-\frac{1}{2})} = u'\left(\hat{w}_{1\varnothing}^R\right)$$

$$\Leftrightarrow \hat{w}_{0\varnothing}^R < \hat{w}_{1\varnothing}^R$$

Given these results, it is easy to see that:

- If $\frac{1}{2} < \rho_v \leq \rho_y$ then $\hat{w}^R_{0B} < \hat{w}^R_{0\varnothing} < \hat{w}^R_{0G} < \hat{w}^R_{1B} < \hat{w}^R_{1\varnothing} < \hat{w}^R_{1G}$
- If $\frac{1}{2} < \rho_y < \rho_v$ then $\hat{w}^R_{0B} < \hat{w}^R_{0\varnothing} < \hat{w}^R_{1B} < \hat{w}^R_{0G} < \hat{w}^R_{1\varnothing} < \hat{w}^R_{1G}$
- If $\rho_v = \frac{1}{2}$ then $\hat{w}^R_{0B} = \hat{w}^R_{0\varnothing} = \hat{w}^R_{0G}$ and $\hat{w}^R_{1B} = \hat{w}^R_{1\varnothing} = \hat{w}^R_{1G}$ ■

Proof of Corollary 3A. We establish the conditions under which the principal is willing to obtain a additional signal through supervision. The principal will supervise the agent as long as the cost of supervision ϕ_s is lower than the benefits obtained from supervision. Formally, the principal will decide to supervise the agent in an efficient equilibrium whenever the following condition holds.

$$(\hat{\mathbf{w}}^R_N)\mathbf{P}^N_1 - (\hat{\mathbf{w}}^R)\mathbf{P}_1 \geq \phi_s$$

where $(\hat{\mathbf{w}}^R_N)\mathbf{P}^N_1 - (\hat{\mathbf{w}}^R)\mathbf{P}_1 > 0$ for any $\rho_v \in (\frac{1}{2}, 1]$. The benefits of supervision follow from the fact that the principal can implement the efficient level of effort with lower wages. Indeed, under supervision the principal has more information available to detect possible shirking behaviors of her subordinate. In fact, in the absence of influence activities, the supervision signal can be said to be valuable for any $\rho_v > \frac{1}{2}$. In that case, the principal will be able to punish the agent severely without reducing his expected utility by keeping constant the variance of wages. ■

Proof of Corollary 1. i) As ρ_v or ρ_y increases the cost of implementing the efficient level of effort decreases. This can be shown using the Blackwell efficiency theorem. We consider the case of ρ_y (the case of ρ_v is symmetric).

We take the following information structure $(\mathbf{P}_1, \mathbf{P}_0)$ that corresponds to the supervision case with $\mathbf{P}_1$ $[\mathbf{P}_0]$ the probability of receiving each of these payments when exerting a high [low] level of effort, that is:

$$\mathbf{P}_1 = \begin{bmatrix} \rho_y \rho_v \\ \rho_y (1-\rho_v) \\ (1-\rho_y)\rho_v \\ (1-\rho_y)(1-\rho_v) \end{bmatrix} \text{ and } \mathbf{P}_0 = \begin{bmatrix} (1-\rho_y)(1-\rho_v) \\ (1-\rho_y)\rho_v \\ \rho_y(1-\rho_v) \\ \rho_y\rho_v \end{bmatrix}$$

Also, we consider the following information structure where the precision of the soft signal is decreased to $\rho_y - \varepsilon$, where $\varepsilon > 0$.

$$\mathbf{P}_{1\varepsilon} = \begin{bmatrix} (\rho_y - \varepsilon)\rho_v \\ (\rho_y - \varepsilon)(1-\rho_v) \\ (1-\rho_y+\varepsilon)\rho_v \\ (1-\rho_y+\varepsilon)(1-\rho_v) \end{bmatrix} \text{ and } \mathbf{P}_{0\varepsilon} = \begin{bmatrix} (1-\rho_y+\varepsilon)(1-\rho_v) \\ (1-\rho_y+\varepsilon)\rho_v \\ (\rho_y-\varepsilon)(1-\rho_v) \\ (\rho_y-\varepsilon)\rho_v \end{bmatrix}$$

If we are able to show that the information structure $(\mathbf{P}_1, \mathbf{P}_0)$ is sufficient, in the sense of Blackwell, for the information structure $(\mathbf{P}_{1\varepsilon}, \mathbf{P}_{0\varepsilon})$ for $\varepsilon > 0$ then we can conclude using the Blackwell sufficiency theorem that the cost of implementing the efficient level of effort decreases in ρ_y.

To show that $(\mathbf{P}_1, \mathbf{P}_0)$ is sufficient, in the sense of Blackwell, for $(\mathbf{P}_{1\varepsilon}, \mathbf{P}_{0\varepsilon})$ we have to show that there exists a transition matrix $Q = (q_{ij}), (i,j) \in \{1,...,4\}^2$ that is independent of the level of effort such that $p_{j1\varepsilon} = \sum_{j=1}^{4} q_{ij} p_{j1}$ and $p_{j0\varepsilon} = \sum_{j=1}^{4} q_{ij} p_{j0}$.

This can be shown taking the following transition matrix:

$$Q = \begin{bmatrix} 1 - \frac{\varepsilon}{2\rho_y - 1} & 0 & \frac{\varepsilon}{2\rho_y - 1} & 0 \\ 0 & 1 - \frac{\varepsilon}{2\rho_y - 1} & 0 & \frac{\varepsilon}{2\rho_y - 1} \\ \frac{\varepsilon}{2\rho_y - 1} & 0 & 1 - \frac{\varepsilon}{2\rho_y - 1} & 0 \\ 0 & \frac{\varepsilon}{2\rho_y - 1} & 0 & 1 - \frac{\varepsilon}{2\rho_y - 1} \end{bmatrix}$$

ii) The rest of the Corollary is derived from the previous results, taking into account that the benchmark model corresponds to the case in which $\rho_v = \frac{1}{2}$. Indeed only for $\rho_v = \frac{1}{2}$ we have that $\hat{w}^R_{0B} = \hat{w}^R_{0\varnothing} = \hat{w}^R_{0G}$ and $\hat{w}^R_{1B} = \hat{w}^R_{1\varnothing} = \hat{w}^R_{1G}$ (see Corollary 2A). This implies that cost of implementing the efficient level of effort for any $\rho_v \neq \frac{1}{2}$ is strictly lower than in the benchmark model. ■

Proof of Lemma 1A. The soft signal should be included in the optimal contract whenever the cost of supervision ϕ_s is smaller than the benefits obtained from supervising the agent. These benefits correspond to the reduction in the expected wages that the principal has to pay to incentivate the agent to exert a high level of effort. We denote $\mathbf{w}^I = \left[w^I_{1,G}, w^I_{1,B}, w^I_{0,G}, w^I_{0,B}\right]$ the vector of contingent wages under influence and $\mathbf{P}^I_1$ the probability of receiving each of these payments when the agent undertakes the influence activity, where

$$\mathbf{P}^I_1 := \left(p^1_{i1}\right)_{i \in \{1,\ldots,4\}} = \begin{bmatrix} \rho_y[\rho_v + \pi(1-\rho_v)] \\ \rho_y(1-\pi)(1-\rho_v) \\ \left(1-\rho_y\right)[\rho_v + \pi(1-\rho_v)] \\ \left(1-\rho_y\right)(1-\pi)(1-\rho_v) \end{bmatrix}$$

We first establish the general condition under which it is optimal for the principal to supervise her subordinate in the case of influence:

$$(\hat{\mathbf{w}}^R_N)\mathbf{P}^N_1 - (\hat{\mathbf{w}}^{\mathbf{I}})\mathbf{P}^I_1 \geq \phi_s$$

If the condition above holds, contingent wages will depend on both signals. Consider the case of an efficient equilibrium $(\hat{e} = e_H)$. In that context, if the principal allows for influence, the agent can undertake the influence activity and receive the wages in $\mathbf{w}^I = \left[w^I_{1,G}, w^I_{1,B}, w^I_{0,G}, w^I_{0,B}\right]$ with probability $\mathbf{P}^I_1$. If the agent does not undertake the influence activity, then the probability of receiving these wages is given by:

$$\mathbf{P}_1 = (p_{i1})_{i\in\{1,\dots,4\}} = \begin{bmatrix} \rho_y\rho_v \\ \rho_y(1-\rho_v) \\ \left(1-\rho_y\right)\rho_v \\ \left(1-\rho_y\right)(1-\rho_v) \end{bmatrix}$$

Therefore, the agent undertakes the influence activity if and only if

$u\left(\mathbf{w}^I\right)^\top\left(\mathbf{P}_1^I - \mathbf{P}_1\right) > \phi_a$.

That is,

(IA) $\rho_y\left[u\left(w_{1G}^I\right) - u\left(w_{1B}^I\right)\right] + (1-\rho_y)\left[u\left(w_{0G}^I\right) - u\left(w_{0B}^I\right)\right] > \frac{\phi_a}{\pi(1-\rho_v)}$

This condition states that the agent will undertake the influence activity as long as the benefits derived from increasing the probability of receiving a high pay w_{yG} instead of getting a low pay w_{yB} (where $w_{yB} < w_{yG}$ for any $y \in \{0,1\}$) are larger than the cost of the influence activity (ϕ_a). We can see in condition (IA) that as the quality of the hard signal $\left(\rho_y\right)$ rises, the incentives for the agent to undertake the influence activity decrease. This occurs because as ρ_y increases, the distortion of the soft signal which is achieved through influence activities becomes less effective. For example, the soft signal will be ignored by the principal if the hard signal is perfectly accurate ($\rho_y = 1$). Finally, notice that an increase in the principal's bias (π) facilitates influence activities as it lowers the right-hand side in condition (IA). The intuitive reasoning is that an increase in π raises the manipulability of the soft signal so that the probability with which influence activities turn a low pay (w_{yB}) into a high pay (w_{yG}) increases as well. ■

Proof of Proposition 1A. If the Principal supervises under influence: $v_s \in \{B, G\} = v$ with probability $(1-\pi)$ and $v_S = G$ otherwise. Recall that the optimal contract cannot depend on the influence activity $a \in \{0,1\}$ because it is unverifiable. We denote the optimal contingent contract under influence $\hat{\mathbf{w}}^I = \left[\hat{w}_{1,G}^I, \hat{w}_{1,B}^I, \hat{w}_{0,G}^I, \hat{w}_{0,B}^I\right]^\top$ and denote P_1^I $\left[\mathbf{P}_0^I\right]$ the probability of receiving each of these payments when exerting a high [low] level of effort. Thus,

$$\mathbf{P}_1^I := \left(p_{i1}^I\right)_{i\in\{1,\dots,4\}} = \begin{bmatrix} \rho_y[\rho_v + \pi(1-\rho_v)] \\ \rho_y(1-\pi)(1-\rho_v) \\ \left(1-\rho_y\right)[\rho_v + \pi(1-\rho_v)] \\ \left(1-\rho_y\right)(1-\pi)(1-\rho_v) \end{bmatrix}$$

and $$\mathbf{P}_0^I := \left(p_{i0}^I\right)_{i\in\{1,\dots,4\}} = \begin{bmatrix} \left(1-\rho_y\right)(1-\rho_v+\pi\rho_v) \\ \left(1-\rho_y\right)\rho_v(1-\pi) \\ \rho_y(1-\rho_v+\pi\rho_v) \\ \rho_y\rho_v(1-\pi) \end{bmatrix}.$$

The first part of the proposition is to show that the signal v_s is informative about the agent's level of effort whenever $\rho_v > \frac{1}{2}$ and $\pi < 1$. Recall that $P[v_s = G \mid e = e_L] = 1 - \rho_v + \pi\rho_v$ and $P[v_s = G \mid e = e_H] = \rho_v + \pi(1-\rho_v)$. Since, $P[v_s = G \mid e = e_L] < P[v_s = G \mid e = e_H]$ for any $\rho_v > \frac{1}{2}$, $\pi < 1$ the result follows (see Laffont and Martimort 2002, Section 4.6.1, p168).

We can then derive the optimal contract under influence ($\hat{\mathbf{w}}^I$) which solves:

$$\begin{cases} (1)\ \hat{\mathbf{w}}^I = \min\limits_{\mathbf{w}\in\mathbb{R}^4} \mathbf{w}\mathbf{P}_1^I \\ \qquad (2)\ \mathbf{u}(\mathbf{w})\,\mathbf{P}_1^I - \phi_e \geq \bar{u} \qquad\qquad \mathbf{IR} \\ \qquad (3)\ \mathbf{u}(\mathbf{w})\,\mathbf{P}_1^I - \phi_e \geq \mathbf{u}(\mathbf{w})\,\mathbf{P}_0^I \quad \mathbf{IC} \end{cases}$$

We can define $u_{1G} = u(w_{1G}^I), u_{1B} = u(w_{1B}^I), u_{0G} = u(w_{0,G}^I)$ and $u_{0B} = u(w_{0,B}^I)$ so that $w_{1G}^I = h(u_{1G})$, $w_{1B}^I = h(u_{1B}), w_{0G}^I = h(u_{0G})$ and $w_{0B}^I = h(u_{0B})$.

Then, the first-order Kuhn-Tucker conditions are necessary and sufficient to determine the optimal contract

$$\begin{cases} (1)\ \hat{\mathbf{w}}^I = \min\limits_{\{(u_0,u_1)\}} p_{11}^I h(u_{1G}) + p_{21}^I h(u_{1B}) + p_{31}^I h(u_{0G}) + p_{41}^I h(u_{0B}) \\ \qquad (2)\ p_{11}^I u_{1G} + p_{21}^I u_{1G} + p_{31}^I u_{1G} + p_{41}^I u_{1G} - \phi_e \geq \bar{u}\ \mathbf{IR} \\ \qquad (3)\ p_{11}^I u_{1G} + p_{21}^I u_{1G} + p_{31}^I u_{1G} + p_{41}^I u_{1G} - \phi_e \geq \\ \qquad\qquad p_{10}^I u_{1G} + p_{20}^I u_{1G} + p_{30}^I u_{1G} + p_{40}^I u_{1G} \qquad \mathbf{IC} \end{cases}$$

We denote λ and μ the non-negative Lagrange multipliers associated respectively with the incentive compatibility (**IC**) constraint and the individual rationality (**IR**) constraint. If we use the arguments in Proposition 1, we conclude that:

$$\begin{cases} (1_{1G})\ u'\left(\hat{w}_{1G}^I\right) = \frac{\rho_y(\rho_v+\pi(1-\rho_v))}{\lambda\rho_y(\rho_v+\pi(1-\rho_v))+\mu(\rho_v+\rho_y-1+\pi(\rho_y-\rho_v))} \\ (1_{1B})\ \ u'\left(\hat{w}_{1B}^I\right) = \frac{\rho_y(1-\pi)(1-\rho_v)}{\lambda\rho_y(1-\pi)(1-\rho_v)+\mu(\pi-1)(\rho_v-\rho_y)} \\ (1_{0G})\quad u'\left(\hat{w}_{0G}^I\right) = \frac{\left(1-\rho_y\right)[\rho_v+\pi(1-\rho_v)]}{\lambda\left(1-\rho_y\right)[\rho_v+\pi(1-\rho_v)]+\mu(\rho_v-\rho_y-\pi(\rho_v+\rho_y-1))} \\ (1_{0B})\quad u'\left(\hat{w}_{0B}^I\right) = \frac{\left(1-\rho_y\right)(1-\pi)(1-\rho_v)}{\lambda\left(1-\rho_y\right)(1-\pi)(1-\rho_v)+\mu(\pi-1)(\rho_v+\rho_y-1)} \end{cases}$$

And notice that $\lim_{\pi\to 0}\ (\hat{\mathbf{w}}^I - \mathbf{w}^R) = \vec{0}$. Indeed, for $\pi = 0$ the optimal contingent contract $\hat{\mathbf{w}}^I = \left[\hat{w}_{1G}^I, \hat{w}_{1B}^I, \hat{w}_{0G}^I, \hat{w}_{0B}^I\right]$ coincides with the optimal scheme under rational supervision $\hat{\mathbf{w}}^R = [\hat{w}_{1G}^R, \hat{w}_{1B}^R, \hat{w}_{0G}^R, \hat{w}_{0B}^R]$. For completeness, we can also observe that $\lim_{\pi\to 1}\ \hat{w}_{1,G}^I - \hat{w}_{1,B}^I = 0$.

If we compare $(1_{1G}), (1_{1B}), (1_{0G})$ and (1_{0B}) above, we get that for any $\rho_v > \frac{1}{2}, \rho_y \in (\frac{1}{2}, 1)$ and $\pi < 1$:

(1) $u'\left(\hat{w}_{1G}^I\right) < u'\left(\hat{w}_{1B}^I\right) < u'\left(\hat{w}_{0B}^I\right) \Leftrightarrow \hat{w}_{1G}^I > \hat{w}_{1B}^I > \hat{w}_{0B}^I$.

(2) $u'\left(\hat{w}_{1G}^I\right) < u'\left(\hat{w}_{0G}^I\right) < u'\left(\hat{w}_{0B}^I\right) \Leftrightarrow \hat{w}_{1G}^I > \hat{w}_{0G}^I > \hat{w}_{0B}^I$

To derive the results in Section 4.1, we need to study whether more weight is assigned to the hard or the soft signal in the optimal contingent contract under influence. This relationship between $\hat{w}_{0G}^I$ and $\hat{w}_{1B}^I$ varies according to the principal's bias (π) and the precision of the signals (ρ_v and ρ_y) and can be derived after equating the likelihood ration associated with the hard and to the soft signal in the case of influence.

Then, we can see that for any $\pi < \bar{\pi} := \frac{\rho_v - \rho_y}{\rho_v + \rho_y - 1}$ we have $\Lambda(\pi, \rho_v, \rho_y, \lambda_0, \mu_0) := u'\left(\hat{w}_{1B}^I\right) - u'\left(\hat{w}_{0G}^I\right) > 0$ therefore $\hat{w}_{1B}^I < \hat{w}_{0G}^I$. The opposite is true when $\pi \geq \bar{\pi}$.

To sum up, if the principal supervises the agent in an efficient equilibrium under influence then $(\hat{\mathbf{w}}^I)\mathbf{P}_1^I - \mathbf{w}_N\mathbf{P}_1^N \leq 0$, where $(\hat{\mathbf{w}}^I)\mathbf{P}_1^I - \mathbf{w_N}\mathbf{P}_1^N = 0$ for $\rho_v = \frac{1}{2}$ or for $\pi = 1$. The optimal wage scheme $\hat{\mathbf{w}}^I$ satisfies the following conditions:

(a) If $\frac{1}{2} < \rho_v \leq \rho_y$ then $\hat{w}_{0B}^I < \hat{w}_{0G}^I \leq \hat{w}_{1B}^I < \hat{w}_{1G}^I$

(b) If $\frac{1}{2} < \rho_y < \rho_v$ then:

i) $\hat{w}_{0B}^I < \hat{w}_{1B}^I \leq \hat{w}_{0G}^I < \hat{w}_{1G}^I$ for $\pi \leq \bar{\pi}(\rho_y, \rho_v) := \frac{\rho_v - \rho_y}{\rho_v + \rho_y - 1}$

ii) $\hat{w}_{0B}^I < \hat{w}_{0G}^I < \hat{w}_{1B}^I < \hat{w}_{1G}^I$ for $\pi > \bar{\pi}(\rho_y, \rho_v)$ ■

Proof of Corollary 4A. In this corollary we introduce some comparative statics and compare the optimal influence contract in the case of cognitive bias $\hat{\mathbf{w}}^I$ and the optimal contract in the case of rational supervision, $\hat{\mathbf{w}}^R$. More precisely, we show that:

i) $\partial \frac{(\hat{\mathbf{w}}^I)\mathbf{P}_1^I - \left(\hat{\mathbf{w}}^R\right)^\top \mathbf{P}_1}{\partial \pi} > 0$

ii) $\partial \frac{(\hat{\mathbf{w}}^I)\mathbf{P}_1^I - \left(\hat{\mathbf{w}}^R\right)^\top \mathbf{P}_1}{\partial \rho_v} > 0$

iii) $\partial \frac{(\hat{\mathbf{w}}^I)\mathbf{P}_1^I - \left(\hat{\mathbf{w}}^R\right)^\top \mathbf{P}_1}{\partial \rho_y} < 0$

The first part *i)* follows from our Proposition 3A below.

For the second part of the corollary *ii & iii)* we show that $\partial \frac{(\hat{\mathbf{w}}^I)^\top \mathbf{P}_1^I - (\mathbf{w}^R)^\top \mathbf{P}_1}{\partial \rho_y} < 0$ (the case for ρ_v follows the same reasoning).

We use the result established by Kim (1995), showing that an information structure $\mathbf{P}$ is more efficient than an information structure $\mathbf{\Pi}$ if its likelihood ratio is a mean preserving spread of that of Π. We compute the following function:

$\Phi\left(\rho_v^p, \rho_v^\pi, \rho_y^p, \rho_y^\pi, \pi\right) := \sum_{i \in S} \left(\frac{\pi_{i0}}{\pi_i 1} - \frac{p_{i0}}{p_i 1}\right)$

Where ρ_i^j stands for the precision of signal $i \in \{v, y\}$ of information structure $j \in \{\mathbf{P}, \mathbf{\Pi}\}$ and $\mathbf{\Pi} := \mathbf{P}^I$ denotes the probability vector under influence.

$\Phi\left(\rho_v, \rho_v, \rho_y, \rho_y, \pi\right) = \left(\frac{\left(1-\rho_y\right)(1-\rho_v+\pi\rho_v)}{\rho_y[\rho_v+\pi(1-\rho_v)]} + \frac{\rho_y(1-\rho_v+\pi\rho_v)}{\left(1-\rho_y\right)[\rho_v+\pi(1-\rho_v)]}\right)$

$-\left(\frac{\left(1-\rho_y\right)(1-\rho_v)}{\rho_y\rho_v} + \frac{\rho_y(1-\rho_v)}{\left(1-\rho_y\right)\rho_v}\right) > 0$

Since $\frac{\partial\Phi\left(\rho_v,\rho_v,\rho_y,\rho_y,\pi\right)}{\partial\rho_y} > 0$ for any $\pi > 0$ and $\frac{\partial^2\Phi\left(\rho_v,\rho_v,\rho_y,\rho_y,\pi\right)}{\partial\rho_y\partial\pi} > 0$.

As a result, for any ρ_y we need for the information structure $\mathbf{\Pi}\left(\pi, \rho_y\right)$ to be as efficient as $\mathbf{P}\left(\rho_v, \rho_y^p\right)$ that $\rho_y^p = \rho_y^-$ where $\rho_y^- < \rho_y$ so that $\Phi\left(\rho_v, \rho_v, \rho_y^=, \rho_y, \pi\right) = 0$. Also, for an increase in ρ_y to ρ_y^+ we know that Φ rises so that $\mathbf{\Pi}\left(\pi, \rho_y^+\right)$ will be as efficient as $\mathbf{P}\left(\rho_v, \rho_y^p\right)$ for $\rho_y^p = \rho_{y_=}$ where $\rho_y^+ - \rho_{y_=} > \rho_y^- - \rho_y$. We conclude that for an increase in ρ_y information systems $\mathbf{\Pi}$ and $\mathbf{P}$ are not affected similarly. In particular, an increase in ρ_y tends to favor information system $\mathbf{P}$ compared to $\mathbf{\Pi}$ since $\frac{\partial^2 \Phi\left(\rho_v,\rho_v,\rho_y,\rho_y,\pi\right)}{\partial \rho_y \partial \pi} > 0$ that is the likelihood ratio of information system $\mathbf{P}$ is increased by a larger amount than the likelihood ratio of information system Π when ρ_y rises.

These results indicate that an increase in the manipulability of the supervision signal reduces its informativeness implying that the cost of implementing the efficient equilibrium increases with the bias of the principal in the case of influence activities compared to the case of rational supervision. Also, an increase in the precision of the soft signal decreases the cost of implementing the efficient equilibrium more significantly in the case of rational supervision than in the case of influence. This is the case, since under influence an increase in the precision of the supervision signal is partially offset by the fact that it can be distorted by the subordinate. Finally, in the presence of influence activities an increase in the precision of the hard signal tends to compensate for the low accuracy of the soft signal. In the extreme case in which the hard signal is perfectly informative $\left(\rho_y = 1\right)$ the principal can infer the level of effort of the agent whether the soft signal is manipulable or not. ■

Proof of Proposition 2A. In this proposition, we aim at characterizing the optimal contracts introduced in Table 1. First, we investigate the properties that are satisfied by the optimal influence contract $\hat{\mathbf{w}}^I = \left[\hat{w}^I_{1G}, \hat{w}^I_{1B}, \hat{w}^I_{0G}, \hat{w}^I_{0B}\right]$. If we use the Implicit function theorem in equations $(1_{1G}), (1_{1B}), (1_{0G})$ and (1_{0B}) in Proposition 1A it is easy to see that

$$\begin{cases} \frac{\partial \hat{w}^I_{1G}}{\partial \pi} = \frac{-(2\rho_v-1)(\rho_y-1)\rho_y\mu}{u''\left(\hat{w}^I_{1G}\right)((\pi(\rho_v-1)-\rho_v)\rho_y\lambda+\mu(\rho_v+\rho_y+\pi(\rho_y-\rho_v))^2} < 0 \\ \frac{\partial \hat{w}^I_{0G}}{\partial \pi} = \frac{-(2\rho_v-1)(\rho_y-1)\rho_y\mu}{u''\left(\hat{w}^I_{0B}\right)((\pi(\rho_v-1)-\rho_v)(1-\rho_y)\lambda-\mu(\rho_y-\rho_v+\pi(\rho_y+\rho_v-1))^2} < 0 \end{cases}$$

whereas

$$\begin{cases} \frac{\partial \hat{w}^I_{1B}}{\partial \pi} = \frac{\partial \hat{w}^I_{0B}}{\partial \pi} = 0 \end{cases}$$

Using these equations, we can also derive the relationship between the wages and the signals' precision.

$$\begin{cases} \frac{\partial \hat{w}^I_{0B}}{\partial \rho_v} = -\frac{(1-\pi^2)(\rho_y-1)\rho_y\mu}{u''\left(\hat{w}^I_{0B}\right)((\pi(\rho_v-1)-\rho_v)(1-\rho_y)\lambda-\mu(\rho_y-\rho_v+\pi(\rho_y+\rho_v-1))^2} > 0 \\ \frac{\partial \hat{w}^I_{0G}}{\partial \rho_v} = -\frac{(\rho_y-1)\rho_y\mu}{u''\left(\hat{w}^I_{0G}\right)(\lambda\left(1-\rho_y\right)[\rho_v+\pi(1-\rho_v)]+\mu(\rho_v-\rho_y-\pi(\rho_v+\rho_y-1)))^2} < 0 \\ \frac{\partial \hat{w}^I_{1B}}{\partial \rho_v} = -\frac{(1-\pi^2)(\rho_y-1)\rho_y\mu}{u''\left(\hat{w}^I_{1B}\right)(\lambda\rho_y(1-\pi)(1-\rho_v)+\mu(\pi-1)(\rho_v-\rho_y))^2} > 0 \\ \frac{\partial \hat{w}^I_{1G}}{\partial \rho_v} = -\frac{(\rho_y-1)\rho_y\mu}{u''\left(\hat{w}^I_{1G}\right)((\pi(\rho_v-1)-\rho_v)\rho_y\lambda+\mu(\rho_v+\rho_y+\pi(\rho_y-\rho_v))^2} < 0 \end{cases}$$

And

$$\begin{cases} \frac{\partial \hat{w}^I_{0B}}{\partial \rho_y} = \frac{(\pi(\rho_v-1)-\rho_v)(1+(\pi-1)\rho_v)\mu}{u''\left(\hat{w}^I_{0B}\right)((\pi(\rho_v-1)-\rho_v)(1-\rho_y)\lambda-\mu(\rho_y-\rho_v+\pi(\rho_y+\rho_v-1))^2} > 0 \\ \frac{\partial \hat{w}^I_{0G}}{\partial \rho_y} = \frac{(\rho_v-1)\rho_v\mu}{u''\left(\hat{w}^I_{0G}\right)(\lambda\left(1-\rho_y\right)[\rho_v+\pi(1-\rho_v)]+\mu(\rho_v-\rho_y-\pi(\rho_v+\rho_y-1)))^2} > 0 \\ \frac{\partial \hat{w}^I_{1B}}{\partial \rho_y} = -\frac{(\pi(\rho_v-1)-\rho_v)(1+(\pi-1)\rho_v)\mu}{u''\left(\hat{w}^I_{1B}\right)(\lambda\rho_y(1-\pi)(1-\rho_v)+\mu(\pi-1)(\rho_v-\rho_y))^2} < 0 \\ \frac{\partial \hat{w}^I_{1G}}{\partial \rho_y} = -\frac{(\rho_v-1)\rho_v\mu}{u''\left(\hat{w}^I_{1G}\right)((\pi(\rho_v-1)-\rho_v)\rho_y\lambda+\mu(\rho_v+\rho_y+\pi(\rho_y-\rho_v))^2} < 0 \end{cases}$$

As a result, we conclude that the optimal influence contract that implements the efficient equilibrium satisfies the condition that an increase in the principal's bias (π) raises the weight that is assigned to the hard signal and that the power of incentives decreases in the soft signal (v_s) with respect to the principal's bias (π).

There exists the possibility for the principal to deter manipulation attempts in the case of cognitive bias. The optimal contract to detract workers from the influence activity ($\hat{\mathbf{w}}^F$) in that context solves:

$$\begin{cases} (1)\ \hat{\mathbf{w}}^F = \min\limits_{\mathbf{w}_i \in \mathbb{R}^4} (\mathbf{w}^F)\mathbf{P}_1 & \\ (2)\ \mathbf{u}\left(\mathbf{w}^F\right)\mathbf{P}_1 - \phi_e \geq \bar{u} & \textbf{IR} \\ (3)\ \mathbf{u}\left(\mathbf{w}^F\right)\mathbf{P}_1 - \phi_e \geq \mathbf{u}\left(\mathbf{w}^F\right)\mathbf{P}_0 & \textbf{IC} \\ (4)\ \mathbf{u}\left(\mathbf{w}^F\right)\mathbf{P}_1 \geq \mathbf{u}\left(\mathbf{w}^F\right)\mathbf{P}_1^{\iota} - \phi_a & \textbf{IF} \end{cases}$$

The non-negative Lagrange multipliers are denoted $\lambda > 0$, $\mu > 0$ and $\delta > 0$. We know that all of them are positive because $\mathbf{w}^R$ is not a solution to the optimization problem. We consider the change of variable $u_{1G} = u(w^F_{1G}), u_{1B} = u(w^F_{1B}), u_{0G} = u(w^F_{0G})$ and $u_{0B} = u(w^F_{0B})$ to ensure concavity. We then solve for $\hat{\mathbf{w}}^F$ and get:

$$\begin{cases} (1_{1G})\, u'\left(\hat{w}^F_{1G}\right) = \frac{\rho_y\rho_v}{\lambda\rho_y\rho_v+\mu(\rho_y+\rho_v-1)+\delta\left(\pi(\rho_v-1)\rho_y\right)} \\ (1_{1B})\, u'\left(\hat{w}^F_{1B}\right) = \frac{(1-\rho_v)\rho_y}{\lambda(1-\rho_v)\rho_y+\mu\left(\rho_y-\rho_v\right)+\delta\pi\rho_y(1-\rho_v)} \\ (1_{0G})\ \ u'\left(\hat{w}^F_{0G}\right) = \frac{\left(1-\rho_y\right)\rho_v}{\lambda\left(1-\rho_y\right)\rho_v+\mu\left(\rho_v-\rho_y\right)+\delta\pi\left(\rho_y+\rho_v-1-\rho_y\rho_v\right)} \\ (1_{0B})\, u'\left(\hat{w}^F_{0B}\right) = \frac{\left(1-\rho_y\right)(1-\rho_v)}{\lambda\left(1-\rho_y\right)(1-\rho_v)+\mu(1-\rho_y-\rho_v)+\delta\pi(\rho_v-1)(\rho_y-1)} \end{cases}$$

Therefore, we can show that:

$$(1_{1G})\ \frac{\partial \hat{w}^F_{1G}}{\partial \pi} = -\frac{(\rho_v-1)\rho_v\rho_y^2\delta}{u''\left(\hat{w}^F_{1G}\right)(\pi(\rho_v-1)\rho_y\delta+\rho_v\rho_y\lambda+(\rho_y+\rho_v-1)\mu)^2} < 0$$

$$(1_{1B})\ \frac{\partial \hat{w}^F_{1B}}{\partial \pi} = -\frac{(\rho_v-1)^2\rho_y^2\delta}{u''\left(\hat{w}^F_{1B}\right)((\lambda+\pi\delta)(\rho_v-1)\rho_y+\mu(\rho_v-\rho_y))^2} > 0$$

$$(1_{0G})\ \frac{\partial \hat{w}^F_{0G}}{\partial \pi} = -\frac{(\rho_v-1)\rho_v(1-\rho_y)^2\delta}{u''\left(\hat{w}^F_{0G}\right)((\rho_y-1)(\pi(\rho_v-1)\delta+\rho_v\lambda)+(\rho_y-\rho_v)\mu)^2} < 0$$

$$(1_{0B})\ \frac{\partial \hat{w}^F_{0B}}{\partial \pi} = -\frac{(\rho_v-1)^2(\rho_y-1)^2\delta}{u''\left(\hat{w}^F_{0B}\right)((\lambda+\pi\delta)(\rho_v-1)(\rho_y-1)-\mu(\rho_v+\rho_y-1))^2} > 0$$

Similarly, we can derive the results for $\frac{\partial \hat{\mathbf{w}}^F}{\partial \rho_y}$ and $\frac{\partial \hat{\mathbf{w}}^F}{\partial \rho_v}$ by using the implicit function theorem. The main results are reported in Table 1. ■

Proof of Proposition 3A. We use the result established by Kim (1995), showing that an information structure $\mathbf{P}$ is more efficient than an information structure $\mathbf{\Pi}$ if its likelihood ratio is a mean preserving spread of that of $\mathbf{\Pi}$.

We compute the following function:

$$\Phi\left(\rho^p_v, \rho^\pi_v, \rho^p_y, \rho^\pi_y, \pi\right) := \sum_{i\in S}\left(\frac{p^I_{i0}}{p^I_i 1} - \frac{p_{i0}}{p_i 1}\right)$$

Where ρ^j_i stands for the precision of signal $i \in \{v, y\}$ of information structure $j \in \{\mathbf{P}, \mathbf{\Pi}\}$ and $\Pi := \mathbf{P}^I$ denotes the probability vector under influence.

$$\Phi\left(\rho_v,\rho_v,\rho_y,\rho_y,\pi\right)=\left(\frac{\left(1-\rho_y\right)\left(1-\rho_v+\pi\rho_v\right)}{\rho_y[\rho_v+\pi(1-\rho_v)]}+\frac{\rho_y(1-\rho_v+\pi\rho_v)}{\left(1-\rho_y\right)[\rho_v+\pi(1-\rho_v)]}\right)$$
$$-\left(\frac{\left(1-\rho_y\right)(1-\rho_v)}{\rho_y\rho_v}+\frac{\rho_y(1-\rho_v)}{\left(1-\rho_y\right)\rho_v}\right)>0$$

Since $\frac{\partial\left(\frac{\left(1-\rho_y\right)\left(1-\rho_v+\pi\rho_v\right)}{\rho_y[\rho_v+\pi(1-\rho_v)]}+\frac{\rho_y(1-\rho_v+\pi\rho_v)}{\left(1-\rho_y\right)[\rho_v+\pi(1-\rho_v)]}\right)}{\partial\pi}>0$. At the same time, we have that $\frac{\partial\left(\frac{\left(1-\rho_y\right)(1-\rho_v)}{\rho_y\rho_v}+\frac{\rho_y(1-\rho_v)}{\left(1-\rho_y\right)\rho_v}\right)}{\partial\rho_v}<0$. As a result, for any increase in the influence parameter from π^- to π^+ the information structure $\mathbf{P}\left(\rho_v\right)$ is not as efficient as $\mathbf{\Pi}\left(\pi^+,\rho_v\right)$ since then $\Phi>0$. In order to make $\mathbf{\Pi}\left(\pi^+,\rho_v\right)$ as efficient as $\mathbf{P}$ we can consider the information structure $\mathbf{P}\left(\rho_v^-\right)$ where $\rho_v^-<\rho_v$ so that $\Phi\left(\rho_v^-,\rho_v,\rho_y,\rho_y,\pi^+\right)=0$. As a result any increase in π reduces the efficiency of the information structure $\mathbf{\Pi}$.

Proof of Proposition 2. We denote $\mathbf{P}_1^\iota:=\left(p_{i1}^\iota\right)_{i\in\{1,\ldots,4\}}$ the probability vector when the agent undertakes the influence activity in the context of influence costs.

That is, $\mathbf{P}_1^\iota:=\left(p_{i1}^\iota\right)_{i\in\{1,\ldots,4\}}=\begin{bmatrix}(1-\alpha)\,\rho_y[\rho_v+\pi(1-\rho_v)]\\(1-\alpha)\,\rho_y(1-\pi)\,(1-\rho_v)\\\left[1-(1-\alpha)\,\rho_y\right][\rho_v+\pi(1-\rho_v)]\\\left[1-(1-\alpha)\,\rho_y\right](1-\pi)\,(1-\rho_v)\end{bmatrix}$ ■

and $\mathbf{P}_0^\iota:=\left(p_{i0}^\iota\right)_{i\in\{1,\ldots,4\}}=\begin{bmatrix}(1-\alpha)\left(1-\rho_y\right)(1-\rho_v+\pi\rho_v)\\(1-\alpha)\left(1-\rho_y\right)\rho_v(1-\pi)\\\left[\alpha+(1-\alpha)\,\rho_y\right](1-\rho_v+\pi\rho_v)\\\left[\alpha+(1-\alpha)\,\rho_y\right]\rho_v(1-\pi)\end{bmatrix}$

We then have that:

$$\begin{cases}(1_{1B})\ \ u'\left(\hat{w}_{1G}^\iota\right)=\frac{1}{\lambda+\mu(1-\frac{p_{10}^\iota}{p_{11}^\iota})}\\(1_{1B})\ \ u'\left(\hat{w}_{1B}^\iota\right)=\frac{1}{\lambda+\mu(1-\frac{p_{20}^\iota}{p_{21}^\iota})}\\(1_{0G})\ \ u'\left(\hat{w}_{0G}^\iota\right)=\frac{1}{\lambda+\mu(1-\frac{p_{30}^\iota}{p_{31}^\iota})}\\(1_{0B})\ \ u'\left(\hat{w}_{0B}^\iota\right)=\frac{1}{\lambda+\mu(1-\frac{p_{30}^\iota}{p_{31}^\iota})}\end{cases}$$

By taking derivatives and using simple algebra we get the results summarized in the proposition. ■

Proof of Proposition 3. It is optimal for the principal to design influence-free contracts as long as: $\alpha R(y)+\left(\mathbf{w}^\iota\right)\mathbf{P}_1^\iota\geq\left(\mathbf{w}^f\right)\mathbf{P}_1$. Also, we know by using a very similar proof to the one presented for Proposition 3A that $\left(\mathbf{w}^\iota\right)\mathbf{P}_1^\iota$ is increasing in both α and π and decreasing in the precision of both signals ρ_v and ρ_y. We then conclude that as α increases not only influence contracts tend to be more expansive but revenues will also decrease ($\alpha R(y)$ rises).

The cost of implementing the efficient level of effort in the case of influence-free contracts depends on the solution to the following optimization program:

$$\begin{cases} (1)\ \hat{\mathbf{w}}^f = \min\limits_{\mathbf{w}_i \in \mathbb{R}^4} (\mathbf{w}^f)\mathbf{P}_1 \\ (2)\ \mathbf{u}\left(\mathbf{w}^f\right)\mathbf{P}_1 - C \geq \bar{u} & \mathbf{IR} \\ (3)\ \mathbf{u}\left(\mathbf{w}^f\right)\mathbf{P}_1 - C \geq \mathbf{u}\left(\mathbf{w}^f\right)\mathbf{P}_0 & \mathbf{IC} \\ (4)\ \mathbf{u}\left(\mathbf{w}^f\right)\mathbf{P}_1 \geq \mathbf{u}\left(\mathbf{w}^f\right)\mathbf{P}_1^\iota & \mathbf{IF} \end{cases}$$

We consider that the influence-free constraint (**IF**) is binding, that is the efficient contract $\hat{\mathbf{w}}^R$ is not a solution to the optimization problem with influence. We denote $IF = \mathbf{u}\left(\mathbf{w}^f\right)(\mathbf{P}_1 - \mathbf{P}_1^\iota)$. Also, by simple algebra we get the following comparative statics:

i) $\frac{\partial IF}{\partial \alpha} > 0$, *ii)* $\frac{\partial IF}{\partial \pi} < 0$, *iii)* $\frac{\partial IF}{\partial \rho_v} > 0$, *iv)* $\frac{\partial IF}{\partial \rho_y} > 0$ for low values of π whereas $\frac{\partial IF}{\partial \rho_y} < 0$ for π high. As a result, an increase in α will increase the costs of choosing influence contracts since both $\alpha R(y)$ and $(\mathbf{w}^\iota)\mathbf{P}_1^\iota$ increase in α but also $\left(\mathbf{w}^f\right)\mathbf{P}_1$ decrease in α since the influence-restriction becomes looser as α increases.

- We conclude that there exists a level $\alpha_f \in, (0,1]$ above which the principal will always choose to design influence-free contracts. Indeed, for the upper bound $\alpha = 1$ we know that influence-free contracts are the only solution since then the principal obtains no revenues from the agent.

- Also, as the ability of the worker increases the only part of the inequation that is affected is $\alpha R(y)$ so that there exists a level of ability, say y_f, above which the principal will decide to design influence-free contracts.

- Concerning π, there exist two opposite effects. First an increase in π rises the costs of implementing influence contracts but at the same time it tends to render more attractive the influence activity so that $\frac{\partial IF}{\partial \pi} < 0$ meaning that influence-free contracts become more costly as π rises. ■

Proof of Proposition 4. We need to solve the following optimization problem.

$$\begin{cases} (1)\ \hat{\mathbf{w}}^f = \min\limits_{\mathbf{w} \in \mathbb{R}^4} (\mathbf{w}^f)\mathbf{P}_1 \\ (2)\ \mathbf{u}\left(\mathbf{w}^f\right)\mathbf{P}_1 - \phi_e \geq \bar{u} & \mathbf{IR} \\ (3)\ \mathbf{u}\left(\mathbf{w}^f\right)\mathbf{P}_1 - \phi_e \geq \mathbf{u}\left(\mathbf{w}^f\right)\mathbf{P}_0 & \mathbf{IC} \\ (4)\ \mathbf{u}\left(\mathbf{w}^f\right)\mathbf{P}_1 \geq \mathbf{u}\left(\mathbf{w}^f\right)\mathbf{P}_1^\iota & \mathbf{IF} \end{cases}$$

We get the following first order conditions, where δ is the non-negative Lagrange multiplier associated with restriction **IF**. It is easy to see that $\lambda > 0$, $\mu > 0$ and $\delta > 0$ as long as $\hat{\mathbf{w}}^R$ is not a solution to the optimization problem.

$$\begin{cases} (1_{1G})\ u'\left(\hat{w}_{1G}^f\right) = \frac{\rho_y \rho_v}{\lambda \rho_y \rho_v + \mu(\rho_y + \rho_v - 1) + \delta\left(\rho_y \rho_v - (1-\alpha)\rho_y \rho_v - \pi(1-\alpha)\rho_y(1-\rho_v)\right)} \\ (1_{1B})\ u'\left(\hat{w}_{1B}^f\right) = \frac{(1-\rho_v)\rho_y}{\lambda(1-\rho_v)\rho_y + \mu\left(\rho_y - \rho_v\right) + \delta\rho_y(1-\rho_v)(1-(1-\alpha)(1-\pi))} \\ (1_{0G})\ u'\left(\hat{w}_{0G}^f\right) = \frac{\left(1-\rho_y\right)\rho_v}{\lambda\left(1-\rho_y\right)\rho_v + \mu\left(\rho_v - \rho_y\right) + \delta\left(\left(1-\rho_y\right)\rho_v - \left(1-(1-\alpha)\rho_y\right)(\rho_v + \pi(1-\rho_v))\right)} \\ (1_{0B})\ u'\left(\hat{w}_{0B}^f\right) = \frac{\left(1-\rho_y\right)(1-\rho_v)}{\lambda\left(1-\rho_y\right)(1-\rho_v) + \mu(1-\rho_y-\rho_v) + \delta(1-\rho_v)\left(1-\rho_y - \left(1-(1-\alpha)\rho_y\right)(1-\pi)\right)} \end{cases}$$

If we use the Implicit function theorem in these equations we can see that:

$$\begin{cases} (1_{1G}) \ \frac{\partial \hat{w}_{1G}^{f}}{\partial \pi} = -\frac{(\rho_v-1)\rho_v\rho_y^2(\alpha-1)\delta}{u''\left(\hat{w}_{1G}^{f}\right)(\pi(\rho_v-1)\rho_y(\alpha-1)\delta+\rho_v\rho_y(\lambda+\alpha\delta)+(\rho_y+\rho_v-1)\mu)^2} < 0 \\ (1_{1B}) \ \frac{\partial \hat{w}_{1B}^{f}}{\partial \pi} = -\frac{(\rho_v-1)^2\rho_y^2(\alpha-1)\delta}{u''\left(\hat{w}_{1B}^{f}\right)(\pi(\alpha-1)\delta-\alpha\delta-\lambda)(\rho_v-1)\rho_y+\mu(\rho_v-\rho_y))^2} > 0 \\ (1_{0G}) \ \frac{\partial \hat{w}_{0G}^{f}}{\partial \pi} = -\frac{(\rho_v-1)\rho_v(1-\rho_y)^2(1+\rho_y(\alpha-1))\delta}{u''\left(\hat{w}_{0G}^{f}\right)(\pi(\rho_v-1)(1+\rho_v(1-\alpha))\delta-\rho_v\mu+\rho_v(\lambda-\rho_y(\alpha\delta+\lambda)+\mu))^2} < 0 \\ (1_{0B}) \ \frac{\partial \hat{w}_{0B}^{f}}{\partial \pi} = -\frac{(\rho_v-1)^2(\rho_y-1)((\rho_y(\alpha-1)+1))\delta}{u''\left(\hat{w}_{0B}^{f}\right)((\rho_v-1)(\pi(1+\rho_y(\alpha-1))\delta+\lambda-\rho_v(\alpha\delta+\lambda))+\mu(\rho_v+\rho_y-1))^2} > 0 \end{cases}$$

Similarly, we conclude after some algebra that:

$$\begin{cases} (1_{1G}) \ \frac{\partial \hat{w}_{1G}^{f}}{\partial \alpha} > 0 \text{ for } \alpha > \alpha_1, \text{ where } \alpha_1 = \frac{\pi(1-\rho_v)}{(1-\pi)\rho_v+\pi}. \\ (1_{1B}) \ \frac{\partial \hat{w}_{1B}^{f}}{\partial \alpha} > 0 \text{ for any } \alpha > 0. \\ (1_{0G}) \ \frac{\partial \hat{w}_{0G}^{f}}{\partial \alpha} < 0 \text{ for any } \alpha > 0. \\ (1_{0B}) \ \frac{\partial \hat{w}_{0B}^{f}}{\partial \alpha} < 0 \text{ for any } \alpha > \alpha_0, \text{ where } \alpha_0 = \frac{\pi\left(1-\rho_y\right)}{(1-\pi)\rho_y}. \end{cases}$$

We summarize these results as follows:

i) For $\alpha < \alpha_f$, there exists wage compression as the power of incentives decreases both in the hard and the soft signal with respect to the influence parameter α.

ii) For $\alpha \geq \alpha_f$, the power of incentives increases in the hard signal with respect to the the influence parameter α.

iii) For $\alpha < \alpha_0 \leq \alpha_1$ [$\alpha < \alpha_1 < \alpha_0$], the power of incentives decreases in the soft signal with respect to the influence parameter α.

iv) For $\alpha \geq \alpha_0 > \alpha_1$ [$\alpha > \alpha_1 \geq \alpha_0$], the power of incentives increases in the hard signal with respect to the influence parameter α. ■

Proof of Corollary 2. It follows from the last proposition since for any $\alpha \geq \bar{\alpha}$, there exists a level of productivity $\bar{R} := R(\alpha)$ such that high-productivity agents ($R \geq \bar{R}$) gets an influence-free contract whereas low-productivity agents ($R < \bar{R}$) get an influence contract. Regarding the variance of wages one can see the wage scheme as a mixed Bernoulli distribution with parameter ζ so that the variance of wages $\sigma^2(w)$ in that case is such that: $\sigma^2(w) = \zeta\sigma^2(B_G) + (1-\zeta)\,\sigma^2(B_B) + \zeta\,(1-\zeta)\,[E(B_G) - E(B_G)]^2$ where $B_G\,[B_B]$ is the Bernoulli distribution that takes values w_{1G} and w_{1B} [w_{0G} and w_{0B}] with probability ρ_y and $\left(1-\rho_y\right)$ respectively. To show that $\sigma^2(w)$ increase in α we are left to demonstrate that $\frac{\partial}{\partial\alpha}[E(B_G) - E(B_G)] \geq 0$, that is to show that $\rho_y\,(w_{1G} - w_{1B}) + \left(1-\rho_y\right)(w_{0G} - w_{0B})$ is increasing in α. We know that as α increases the (IF) constraint is relaxed since costs of influence increase for the agent and at the same time the power of incentives in the hard signal increases in α as we have shown in the previous proposition. As a result, for (IF) to be binding in equilibrium (it has to be the case since $\delta > 0$) it has to be that the benefits associated with influence rise to compensate an increase in costs associated with the influence activity previously mentioned. That is, the power of incentives in the soft signal has to increase with regard to α. This implies that both $(w_{1G} - w_{1B})$ and $(w_{0G} - w_{0B})$ cannot decrease in α. This completes the proof that $\sigma^2(w)$ is increasing in

α. ■

Proof of Corollary 3. This result follows from the results in Proposition 3 and Proposition 4. Notice that free supervision may be detrimental for the principal as long as $\hat{\mathbf{w}}_N^R \mathbf{P}_1 \leq \min\{\left(\hat{\mathbf{w}}^I\right) \mathbf{P}_1^\iota, \left(\hat{\mathbf{w}}^f\right) \mathbf{P}_1\}$. In particular, for $\pi = 1$ we know that $\hat{\mathbf{w}}_N^R \mathbf{P}_1 = \hat{\mathbf{w}}^R \mathbf{P}_1$ and $\hat{\mathbf{w}}^R \mathbf{P}_1 \leq \left(\hat{\mathbf{w}}^f\right) \mathbf{P}_1$. Also, for $\alpha \geq \alpha_f$ we know that $\left(\hat{\mathbf{w}}^f\right) \mathbf{P}_1 = \arg\min\{(\hat{\mathbf{w}}^\iota) \mathbf{P}_1^I; \left(\hat{\mathbf{w}}^f\right) \mathbf{P}_1\}$. As a result, $\hat{\mathbf{w}}_N^R \mathbf{P}_1 \leq \min\{(\hat{\mathbf{w}}^\iota) \mathbf{P}_1^\iota, \left(\hat{\mathbf{w}}^f\right) \mathbf{P}_1\}$ for any $\alpha \geq \alpha_f$ and for any $\pi \geq \pi_0$, where π_0 is such that $\hat{\mathbf{w}}_N^R \mathbf{P}_1 - \hat{\mathbf{w}}^R \mathbf{P}_1 = \left(\hat{\mathbf{w}}^f\right) \mathbf{P}_1 - \hat{\mathbf{w}}^R \mathbf{P}_1$.

For $\alpha < \alpha_f$ we know that $(\hat{\mathbf{w}}^\iota) \mathbf{P}_1^\iota = \arg\min\{(\hat{\mathbf{w}}^\iota) \mathbf{P}_1^\iota, \left(\hat{\mathbf{w}}^f\right) \mathbf{P}_1\}$. We know that $(\hat{\mathbf{w}}^\iota) \mathbf{P}_1^\iota > \hat{\mathbf{w}}^R \mathbf{P}_1$ for any $\pi \geq \pi_1$, where π_1 is such that $(\hat{\mathbf{w}}^\iota) \mathbf{P}_1^\iota = \hat{\mathbf{w}}_N^R \mathbf{P}_1$. ■

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