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Internal and External Information System Choices and Mutual Interdependencies

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Abstract:

In this paper, we consider a one shot principal agent problem. The owner of the firm (principal) hires a manager (agent). As firm value is non-contractible by assumption, an incentive contract is written on accounting income. The manager performs some productive task that increases firm value as well as income but can also engage in earnings management to increase income only.
The owner needs to make several simultaneous choices. First, he needs to decide whether to implement an internal information system (IIS). Second, he has to choose from a set of (external) financial reporting systems that differ with regard to accounting discretion. Third, he needs to specify contracting details.
If an internal information system is implemented it provides the manager with private information about the business environment, which, in turn, affects effort costs. In contrast, the financial reporting system choice affects the effectivity of earnings management activities undertaken by the manager.
In the absence of an internal information system, the agency problem considered is a moral hazard problem that arises from private effort choices of the manager. Implementing an internal information system creates an adverse selection problem on top of the moral hazard problem.
We find that for both problems agency costs increase if the business environment becomes more volatile.
Holding either the IIS choice or the accounting system choice constant, we observe the following: Without an IIS, it is optimal to choose the least discretionary accounting system available. With an IIS it can either be advisable to choose the most or least discretionary accounting system depending on the probability distribution of business environments to be present.
For any given accounting system, the principal implements an IIS if the volatility of the business environment is sufficiently high and v.v. The less discretionary the accounting system, however, the more volatile the business environment needs to be for an IIS to become favorable.
It follows that both, accounting system and IIS choice, are mutually interdependent. E.g. it might be optimal for the principal to choose the most discretionary accounting system along with implementing an IIS. In contrast, it might be optimal not to implement an IIS along with the least discretionary accounting system depending on parameter values.

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1. Introduction

Large firms are typically characterized by a separation of ownership and control. Owners are unable or unwilling to manage the firm themselves and delegate this task to a hired management. Asymmetric information is inevitably present as managers have superior knowledge about the business they operate, the choices they make, the effort they put in.

However, the degree of asymmetric information depends on the internal and external information systems in place.

The most established external information system is certainly the financial reporting system. In most countries, corporations are required to publish financial accounting information in the form of financial statements at least once a year. Even though publication per se is obligatory, there is certainly some discretion regarding the extent of information published, and also regarding the rules to be applied to generate this information. For instance, many firms can choose between different sets of accounting standards such as international standards as opposed to local GAAP. Those systems may differ e.g., in terms of the tightness of standards and/or their degree of conservatism. Even in the absence of any accounting standards choice, there is typically some potential to affect the degree of accounting discretion. It results, e.g., from the firm's auditor choice or from specifications made within the corporate governance system.

With regard to internal information systems, there is even more discretion. Firms can freely decide whether to implement an internal information system at all and if so, they can specify the information produced, in order to guide managerial decision making.

External information systems are meant to reduce information asymmetry and numbers produced serve as performance measures in order to influence managerial decisions. In contrast, internal information systems are typically meant to facilitate decision-making. Providing management with additional information to support high quality decision-making, however, rather increases than decreases information asymmetry.

In this paper, we consider a principal who hires an agent to manage a business. A set of financial reporting standards needs to be chosen and applied. Doing so produces an earnings number available for incentive contracting. In addition, the owner can choose to implement an internal information system (IIS) that is informative about the business environment the firm faces. We analyze, in which way both information systems affect the owners welfare and to what extent choices related to both systems are interdependent.

We assume that the agent can perform two tasks. Personal disutility arising from these tasks differs in the business environment present, which can be good or bad. Note that an agent operating in a good environment can be interpreted as a good type as opposed to a bad type who deals with a bad environment in what follows.

One task is productive in that it increases firm value along with accounting income. The other one increases accounting income only and is referred to as earnings management or window dressing. The set of reporting standards in place affects the sensitivity of accounting earnings to the window dressing activity. The tighter the set of reporting standards, the less effective the agent's earnings management effort.

Moreover, we assume that the accounting system choice affects earnings sensitivity differently depending on the business environment the firm faces. Precisely, we assume that any accounting system restricts earnings management more effectively in the bad state than in the good one. In addition, any tighter set of standards reduces effectiveness more severely if the state is bad than if it is good. This reflects the notion, that more accounting discretion should be present in a good environment. To illustrate, consider typical income reducing accounting events such as the recording of an impairment loss or the recognition of a provision. In a bad state, evidence that indicates an impairment loss is present is probably stronger. Likewise, the probability for a future outflow of resources to occur, that requires recording a provision, is likely to be higher in a bad state than in a good state. It follows that it is harder for a firm to avoid income reducing accounting entries in a bad state than in a good state. Put another way, if the environment is bad, options for window dressing activities still exist, but they are smaller and harder to figure out. In turn, earnings management effort becomes less effective. In our model this effect is stronger, the tighter accounting standards.

The IIS is informative about the business environment present. In the absence of an IIS, manager and principal share common beliefs about probabilities for both states. Accordingly, information symmetry is present when the agent signs the contract. Information asymmetry exists only with regard to the agent's effort choice, resulting in a moral hazard problem. If an IIS is implemented, in contrast, the agent learns the actual state with perfect precision before he signs the contract. Formally, this results in an adverse selection problem on top of the moral hazard problem.

Two of the assumptions made above may appear critical at first sight and probably need some clarification.

First, we assume that implementing an IIS provides the agent with private information even before he signs the contract and actually joins the firm. Doing so, however, is equivalent to assuming that the manager receives information post contract but pre effort choice and is free to resign after having learned the actual state. Obviously, the principal would need to guarantee the manager at least a minimum level of utility in each state to make the agent stay. Using this alternative setting results in identical constraints to be considered as in the setup we use.[1]

Second, we assume that the result from the IIS is observable to the manager, but not to the principal responsible for the implementation choice. Even though this might appear far-fetched in some actual situations, we believe it is compelling in others. E.g. consider a corporation with widespread shareholdings. It is quite reasonable to assume that owners are neither able to observe results from an IIS nor are qualified to interpret them. The same argument holds for decentralized firms in which local managers operate quite independent from headquarters that probably has a say in the decision to implement an IIS, but does not observe the information generated through this IIS later on.

Within the setting described above, we analyze costs and benefits from implementing an IIS along with a set of accounting standards that specifies earnings management efficiency. The principal chooses both systems along with an incentive contract to be offered to the manager.

We find that the IIS choice critically depends on the volatility of the business environment. Precisely, for any given accounting system an IIS becomes more beneficial, the more the disutility incurred for some effort differs in the good state as opposed to the bad state. In fact, without an IIS, the manager

[1] See Rajan and Saouma (2006) for a similar argument.

chooses his effort based on expectations as he is unable to condition his choices on the actual states. As long as the states do not differ too much, however, resulting "errors" are small. If they diverge further, losses from suboptimal effort choices increase and at some point it becomes favorable for the principal to implement an IIS. This allows for state specific effort choices but also creates an adverse selection problem that, in turn, necessitates rent payments to the agent if the state is good.

The adverse selection problem increases in the tightness of accounting standards. In the presence of tighter standards the difference in earnings management effectiveness is larger between types and thus it becomes harder for the principal to keep the good agent type from imitating the bad one. As a consequence, rents to be paid to the good type increase and incentives provided to the bad one decrease in equilibrium. It follows that the critical difference in disutility between states that renders an IIS favorable, as opposed to no IIS, is increasing in the tightness of standards in place. Consequently, there is a larger range of disutility differences in which the principal optimally refrains from implementing an IIS the tighter the accounting system.

In the absence of an IIS, the principal optimally installs the most restrictive accounting system available. A more rigid accounting system renders window dressing more costly and thus shifts the agent's effort towards the productive activity. The congruity problem becomes less severe, which in turn increases firm value and benefits the principal.

If an IIS is installed, in contrast, the principal faces a trade-off with regard to the accounting system choice. A tighter system improves the agent's effort choice in similar fashion to the setting without an IIS. However, it also increases the difference between types and thus enforces the adverse selection problem as described above. Given this trade-off, it depends on the state probabilities whether the most or the least discretionary accounting system is preferred. If the bad state is more likely, the benefits from reducing the congruity problem prevail and the most restrictive accounting system becomes optimal. If the good state is more likely than the bad one, rents need to be paid more often than not to the good type and it turns out favorable for the principal to choose the most discretionary accounting system.

Given these findings, it turns out that it is neither always beneficial to provide the management with decision relevant information nor is it always optimal to restrict earnings management as far as possible. Moreover, we show that optimal choices with regard to the accounting system and implementation of an IIS are not separable. Rather, it depends critically on the set of accounting standards available, whether implementing an IIS pays off.

2. Related literature

Our paper studies the interdependent choices of an accounting system and implementation of an IIS. Formally, we juxtapose a moral hazard type agency problem and one of joint moral hazard and adverse selection. In both settings, the agent performs two unobservable efforts, a productive one and a window dressing activity. The effectivity of the latter is affected by the accounting system in place.

Given these inputs, our model somewhat builds on the classical literature on moral hazard, e.g. Holmström (1979), Grossmann and Hart (1983), and adverse selection such as Laffont and Tirole

(1993). It is also related to the multi-task problems covered in Holmström and Milgrom (1990) and Feltham and Xie (1994).

As the manager in our model performs a window dressing activity that is restricted by a rigid accounting system, our paper has also ties with the literature on earnings management. This includes e.g. Dye (1988), Demski (1998) and Arya, Glover, and Sunder (1998), Liang (2004) and Ewert and Wagenhofer (2005).

Moreover, in this paper the agent reveals private information about his type through his contract choice. This mechanism is equivalent to one in which the agent communicates his type and a contract is assigned based on the report. In this sense, our work is related to papers that study the value of private information dissemination. E.g. Christensen (1981) considers a privately informed agent and investigates under what conditions communication is valuable in the agency. Baiman and Evens (1983) study the value of participation in budgeting given the agent is privately informed. Nafziger (2009) focusses on the optimal timing of information dissemination. More recently, Göx and Michaeli (2019) use a multi task model in which the agent performs a window dressing activity in order to study the value of an information system that generates symmetric information for the principal and the agent. In all of the above studies the agent learns a private signal after he signs the contract. In contrast to our paper, however, all of them assume that the agent commits ex ante to fulfill the contract no matter what signal he observes. Accordingly, no adverse selection problem arises in these studies.

A final stream of literature that ties in with our work comprises studies on joint moral hazard and adverse selection problems. Early work has been done by Sappington (1984) and Melumad and Reichelstein (1989). Both papers investigate the possible value of a menu of contracts as opposed to a single contract offered to all potential types of agents. In both studies, the agent is exogenously endowed with private pre contract information. In contrast, our paper investigates whether it pays off for the principal to provide an agent with this type of information via an IIS, or not to do so.

Imperfect private pre contract information is also present in Rajan and Saouma (2006). In their paper a manager receives a signal that is informative about his type before he signs the contract and chooses his effort. They allow for a continuum of signals and informational states, ranging from perfectly informative to uninformative. They find that either perfect or no information is optimal for the principal, somewhat justifying our simpler setting, that assumes that either a perfect or no signal is present. Moreover, they state that an uninformed manager is preferred if the agent's types are not very distinct. This result is very much in line with our findings regarding an IIS choice for a given accounting system. However, as in their model firm value is contractible a congruity problem similar to ours does not arise. Moreover, an accounting system choice is not included in their paper.

Chen and Leng (2004) consider a risk averse agent and investigate the effect of a joint moral hazard and adverse selection problem on optimal pay for performance sensitivity in a LEN-setting.

Recent studies by Beyer, Guttman, and Marinovic (2014), and Marinovic and Povel (2017) cover not only joint moral hazard and adverse selection problems but simultaneously consider earnings management as we do. These papers are probably closest to our work.

Beyer, Guttman, and Marinovic (2014) consider a setting where an agent performs a productive effort and a window dressing activity. Firm value is non-contractible and earnings is the only performance measure available for contracting. The agent is privately informed about his type, similar to our IIS setting. However, while we assume that the disutility from both efforts differs depending on the agent's type, Beyer et al assume, that this is the case only w.r.t. productive effort. Disutility from window dressing, in contrast, is independent form the agent's type and changes only with the accounting system in place. Even though this particular assumption differs and is critical for their results, their model setup still shows great similarities to our paper. Even a pure moral hazard problem is analyzed in their paper to serve as a benchmark. In contrast to the no IIS setting in our paper, however, both, the principal and the agent are assumed to know the agent's type in their benchmark setting. Thus, the moral hazard problem is coupled with superior information in their paper but comes along with reduced information in ours. Consequently, and in contrast to our results, their moral hazard setting is always preferable to the joint problem. Most important, Beyer et al focus on a research question quite different from ours. They are interested in the shape of the optimal compensation contract and the effects that the agent's ability to manipulate earnings has on this shape, while we focus on interdependencies between accounting system and internal information system choices.

The paper by Marinovic and Povel (2017) also studies the contracting choice of a principal in a joint moral hazard and adverse selection setting which allows for misreporting. The main distinction from our paper is that Marinovic and Povel assume that firms compete for talented managers. They find that competition results in increased incentives. Therefore, it corrects inefficiently low incentives resulting in adverse selection settings due to downward distorted incentives for bad types. However, in the presence of misreporting, competition may also lead to severe over-incentives. Marinovic and Povel (2017) juxtapose the inefficiencies related to the agency problem with and without competition and identify conditions under which competition for talent either benefits or harms the principal.

3. The model

We consider a one shot game between a principal and an agent. The principal makes several choices at the very beginning of the game. To begin with, he specifies a set of accounting standards to be implemented and applied throughout the game. Along with that, he needs to decide whether to implement an IIS that privately informs the manager about the business environment the firm operates in. With these decisions in place, he offers an incentive contract to the agent in order to motivate hard work. Depending on whether an IIS is installed or not, the contract offer might comprise a menu of contracts for the agent to choose from.

The principal aims at maximizing firm value, which is affected by the agent's effort and by the business environment the firm operates in. We assume, however, that firm value itself is un-contractible. For incentive contracting, the principal has to revert to a contractible performance measure, namely accounting income. Accounting income y is affected by two types of efforts, each performed privately by the agent. The first effort is a productive effort in the sense that it increases firm value along with income. The second effort, in contrast, increases the performance measure only and can be referred to as a window dressing activity.[2] If the agent accepts the contract, he provides both efforts and is paid according to his contract at the end of the game.

[2] See e.g. Feltham/Xie (1994) or Goldman/Slezak (2006) for a similar interpretation.

The timeline below summarizes the course of events.

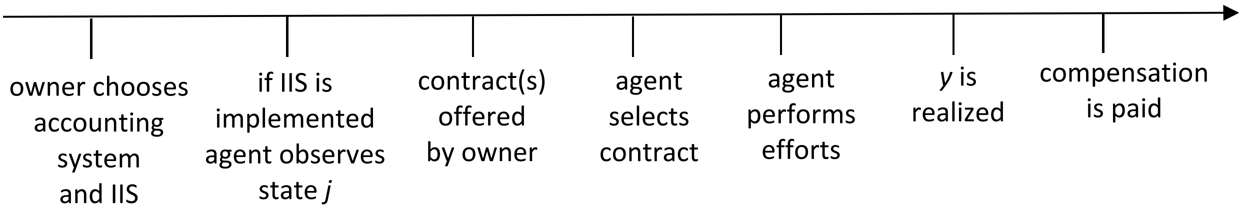

Figure 1: Timeline.

The level of disutility the agent suffers from $C(\boldsymbol{e})$ depends on the business environment the firm faces. It turns out to be good with probability p and bad with $1-p$. Naturally, the good (bad) environment is associated with lower (higher) disutility for the agent. We will refer to an agent operating in the good (bad) state as a good (bad) type where appropriate in what follows. While disutility differs with regard to the type, it is assumed to be identical for both, the productive and the window dressing activity. This reflects the notion that each and every activity becomes more tedious in a tough business environment. Accordingly, we get $C(\boldsymbol{e_j}) = \frac{k_j e_1^2}{2} + \frac{k_j e_2^2}{2}$, with $j = g, b$ and $k_j > 0$. As $k_b > k_g$, we define $k_b = k_g + \Delta$ with $\Delta > 0$.

The accounting income measure $y \in \{y_b, y_g\}$ is defined as follows:

$$y_j = \beta_1 e_1 + \alpha_j \beta_2 e_2 \qquad \text{for } j = b, g.$$

e_1 refers to the productive effort and e_2 is window dressing. β_i, $i = 1{,}2$ depict income sensitivity with regard to both efforts.

α_j captures the tightness of the accounting system in place. The smaller α_j, the tighter the set of standards and the less effective the window dressing activities of the agent. We assume, however, that the accounting system impedes window dressing in different fashion depending on the business environment the firm is operating in. In the good state, $j = g$, there is more potential for accounting discretion than in the bad state, $j = b$. Accordingly, $\alpha_g > \alpha_b$ needs to hold. Moreover, any tighter system goes along with an increase int the spread $\propto_g - \propto_b$. In order to keep the model simple we normalize α_g to one and define $\alpha_b = \alpha$, in what follows.[3] Additionally, we specify $\alpha^{min} = \max\{0, \sqrt{\frac{\beta_2^2 k_g(1-2p) - \Delta p(\beta_1^2 + \beta_2^2)}{\beta_2^2 k_g(1-2p)}}\}$ and $\alpha \in (\alpha^{min}, 1)$.[4]

[3] Using the normalization introduced above, simplifies our analysis without changing the results qualitatively.
[4] This specification is somewhat technical. Intuitively, it allows us to meaningfully interpret the agent operating in the good business environment as the "good type" whereas the agent operating in the bad state is considered the "bad type" no matter what α is present. Note that $\alpha^{min} = 0$ always holds if the good state is more likely than the bad state and that $\alpha^{min} < 1$ holds for all parameter values.

Further, we assume that firm value F increases in e_1 at a similar rate as y does, such that $F = \beta_1 e_1$.

Both, the principal and the agent, are risk neutral and reservation pay is normalized to zero without loss of generality. We allow for linear contracts only. The agent maximizes expected pay less disutility from working hard.

With the above specifications in place, we are ready to introduce consequences from implementing an/no internal information system. As stated above, we assume that such a system provides the manager with private pre-contract information with regard to the business environment the firm operates in.

If no such system is installed, we assume that the agent does not know which working environment is present when he signs the contract. Private information of the agent is limited to post-contract information about effort choice. With regard to the business environment, we assume that both, agent and principal, share common probabilities over both states to occur. As stated above, p is the common ex ante probability for a good environment to be present, while a bad one occurs with probability $(1-p)$. The agency problem without an IIS is a (pure) moral hazard problem. As both players are risk neutral, agency costs result from using an incongruent performance measure, only. Given that earnings management increases y but not F, the agent's equilibrium effort choice differs from first best.

If the IIS is installed, in contrast, it enables the agent to privately observe the type of environment before he accepts the contract. Thus, pre- and post-contracting information asymmetry is present simultaneously, tantamount to an adverse selection problem on top of the moral hazard problem described above.

In what follows we derive optimal contracts in the absence and presence of an IIS. Based on our solutions we will investigate under which circumstances an IIS is favorable and how the accounting system in place affects the results.

4. Optimal contracts in the absence of an IIS

In this setting, no information system is present. Neither the principal nor the agent knows which business environment the firm is operating in. The principal offers a linear incentive contract based on the accounting income y equal to

$$s(y) = f + vy$$

to the agent. f denotes a fixed compensation and v is the incentive rate.

The agent maximizes his expected utility. Superscript 0 refers to the setting without an IIS.

$$\max_{e_1,e_2} EU^0 = E\big(s(y)\big) - E(C(\boldsymbol{e_j}))$$

$$= f + v(\beta_1 e_1 + p\beta_2 e_2 + (1-p)\alpha\beta_2 e_2) - \frac{\bar{k}}{2}(e_1^2 + e_2^2)$$

with $\bar{k} = pk_g + (1-p)(k_g + \Delta)$.

Optimizing w.r.t. e_1 and e_2 we obtain

$e_1^* = \frac{v\beta_1}{\bar{k}}$ and $e_2^* = \frac{v\beta_2(p+(1-p)\alpha)}{\bar{k}}$.

Given the agent's conditionally optimal choice of effort, the principal chooses v and f in order to maximize his expected payoff

$$\max_{v,f} \mathrm{E}\Pi^0 = \beta_1 e_1 - E(s(y_j))$$

$$\text{s.t.} \qquad E(s(y_j)) - E(C(\boldsymbol{e_j})) \geq 0$$

$$e_1 = \frac{v\beta_1}{\bar{k}}$$

$$e_2 = \frac{v\beta_2(p+(1-p)\alpha)}{\bar{k}}$$

Solving the problem results in $v^* = \frac{\beta_1^2}{\beta_1^2+\beta_2^2(p+(1-p)\alpha)^2}$.[5]

Inserting into the optimal effort expressions and the objective function of the principal we obtain lemma 1.

Lemma 1: The optimal solution in the absence of an IIS is characterized by

$$e_1^* = \frac{\beta_1^3}{(pk_g+(1-p)(k_g+\Delta))[\beta_1^2+\beta_2^2(\alpha(1-p)+p)^2]},\ e_2^* = \frac{\beta_1^2\beta_2(\alpha(1-p)+p)}{(pk_g+(1-p)(k_g+\Delta))[\beta_1^2+\beta_2^2(\alpha(1-p)+p)^2]},$$

$$\Pi^{0*} = \frac{\beta_1^4}{(pk_g+(1-p)(k_g+\Delta))[\beta_1^2+\beta_2^2(\alpha(1-p)+p)^2]}.$$

In the absence of an IIS, agency costs arise from suboptimal effort allocation. While the principal is interested in productive effort only, the agent optimally splits his effort between productive effort and the window dressing activity. A congruity problem is present. The problem, however, is less severe the lower the sensitivity of y to window dressing effort, e_2. Sensitivity, of course, is reflected in β_2 and, more important for our analysis, in α. As described above α is a measure of the tightness of the accounting system. Note that the lower α, the more window dressing effort is needed relative to productive effort in order to increase the performance measure in the bad state. As the agent is unaware of the actual state, he shifts more of his activity towards productive effort, the lower α. In turn e_1^* decreases and e_2^* increases in α. The principal, of course, anticipates the agent's effort choices and decreases the incentive rate v^* in α. Accordingly, a lower α results in higher incentives, more

[5] f^* is determined such that the participation constraint is binding at the optimum. We omit to present the explicit result as it does not provide structural insights.

productive effort relative to window dressing effort, and finally a larger expected surplus Π^{0*} for the principal. This is stated in proposition 1 (i).

Proposition 1:

(i) The tighter the set of financial reporting standards in place, that is the lower α, the larger the optimal incentive rate v^* and the principal's expected payoff $E\Pi^{0*}$.

(ii) The larger the difference between the good and bad environment reflected in Δ, the lower $E\Pi^{0*}$.

Moreover, the principal's surplus is critically affected by the extent the states differ, as depicted in (ii) of proposition 1. Recall that by assumption the agent's disutility from effort is lower in the good state than in the bad state. The extent of this difference is captured in $\Delta = k_b - k_g$. The higher Δ, the more the agent's actual effort choice differs from an optimal one conditional on k_j. The lack of effort control reduces the principal's expected surplus from the agency. The optimal incentive rate v^*, in contrast, is unaffected by Δ.

5. Optimal contracts if an IIS is implemented

Now the manager obtains private information via an IIS. As he is perfectly aware of the type of business environment present, he fully controls accounting earnings realized and personal disutility through his effort choices. The principal offers a menu of contracts for the agent to choose from. Each contract specifies an incentive rate and a fixed payment.[6] In our setting such a mechanism without communication is equivalent to a mechanism in which the agent reveals the state to the principal and is offered a linear contract based on this revelation. In equilibrium the contracts are truth revealing. The agent picks the contract designed for the good environment if this is what he has observed from the IIS and v.v.[7] We denote these contracts $s_j(y), j = g, b$ in what follows.

Given the distinct settings, the optimization problem faced by the agent differs with the privately known state.

Starting with the good type, his effort choice problem can be stated as follows:

$$\max_{e_{1g}, e_{2g}} U^g = s_g(y) - C(\boldsymbol{e_g})$$

$$= f_g + v_g(\beta_1 e_{1g} + \beta_2 e_{2g}) - \frac{k_g}{2}(e_{1g}^2 + e_{2g}^2)$$

The agent's optimal effort choice is given by $e_{1g}^* = \frac{v_g \beta_1}{k_g}$ and $e_{2g}^* = \frac{v_g \beta_2}{k_g}$.

[6] See e.g. Chen and Leng (2004) for a similar approach.

[7] Note that the chosen mechanism results in a separating equilibrium as different contracts are chosen in different states. Alternatively, the principal could offer a single contract to be accepted by both types resulting in a pooling equilibrium. It is easy to show, however, that the principal's payoff with separating is larger than with pooling. This is why a pooling mechanism is not further considered.

If the business environment is of type b, his optimization problem becomes

$$\max_{e_{1b},e_{2b}} U^b = s_b(y) - C(\boldsymbol{e_b})$$

$$= f_b + v_b(\beta_1 e_{1b} + \alpha\beta_2 e_{2b}) - \frac{k_b}{2}(e_{1b}^2 + e_{2b}^2)$$

Solving the problem we obtain $e_{1b}^* = \frac{v_b\beta_1}{k_b}$ and $e_{2b}^* = \frac{v_b\alpha\beta_2}{k_b}$.

Note that we have assumed above that both types of agents self-select into the contract designed for them. If they do not, optimal effort differs. This is reflected in the right-hand sides of the self-selection constraints (3) and (4) below.

Given the optimal effort reactions of each type, the principal maximizes expected net payoff, ensuring that the agent is willing to participate and to choose the right contract.

$$\max_{f_g,v_g,f_b,v_b} \mathrm{E}\Pi^{IIS} = p[\beta_1 e_{1g} - s_g(y_g)] + (1-p)[\beta_1 e_{1b} - s_b(y_b)]$$

s.t.

$$f_g + v_g(\beta_1 e_{1g} + \beta_2 e_{2g}) - \frac{k_g}{2}(e_{1g}^2 + e_{2g}^2) \geq 0 \tag{1}$$

$$f_b + v_b(\beta_1 e_{1b} + \alpha\beta_2 e_{2b}) - \frac{k_b}{2}(e_{1b}^2 + e_{2b}^2) \geq 0 \tag{2}$$

$$f_g + v_g\left(\beta_1 e_{1g} + \beta_2 e_{2g}\right) - \frac{k_g}{2}\left(e_{1g}^2 + e_{2g}^2\right) \geq$$

$$f_b + v_b(\beta_1 \frac{v_b\beta_1}{k_g} + \beta_2 \frac{v_b\beta_2}{k_g}) \ - \frac{k_g}{2}((\frac{v_b\beta_1}{k_g})^2 + (\frac{v_b\beta_2}{k_g})^2) \tag{3}$$

$$f_b + v_b(\beta_1 e_{1b} + \alpha\beta_2 e_{2b}) - \frac{k_b}{2}\left(e_{1b}^2 + e_{2b}^2\right) \geq$$

$$f_g + v_g\left(\beta_1 \frac{v_g\beta_1}{k_b} + \beta_2 \frac{v_g\alpha\beta_2}{k_b}\right) - \frac{k_b}{2}((\frac{v_g\beta_1}{k_b})^2 + (\frac{v_g\alpha\beta_2}{k_b})^2) \tag{4}$$

$$e_{1g} = \frac{v_g\beta_1}{k_g}$$

$$e_{2g} = \frac{v_g\beta_2}{k_g}$$

$$e_{1b} = \frac{v_b\beta_1}{k_b}$$

$$e_{2b} = \frac{v_b \alpha \beta_2}{k_b}$$

Constraints (1) and (2) ensure that the agent is willing to work for the firm. (3) and (4) are self-selection constraints.

It is well known from previous literature that not all of the constraints are binding at the optimum.[8] Intuitively, we expect (1) to be non-binding as the good type agent receives a rent payment. The rent motivates him to self-select into the good state contract rather than to pretend that the bad state is present. Optimally, the minimal rent that prevents imitation of the bad state is paid. It follows that (3) is expected to be binding. In case of the bad state, imitating the good one is too expensive and therefore we presume (4) is not binding. As a consequence, the bad type agent can be kept at his reservation utility level, such that (2) would be binding.

Using the intuition above, we solve the optimization problem ignoring conditions (1) and (4) in what follows. Once optimal solutions are derived, however, we insert them into (1) and (4) in order to ensure both conditions are indeed non-binding at the optimum.[9] Maximizing the reduced problem with respect to v_g and v_b we obtain the following expressions:

$$v_g^* = \frac{\beta_1^2}{\beta_1^2 + \beta_2^2}$$

$$v_b^* = \frac{\beta_1^2 k_g (1-p)}{\beta_1^2 [\, k_g (1-p) + \Delta p] + \beta_2^2 [\big(k_g + \Delta\big) p + \alpha^2 k_g (1-2p)]}$$

Inserting into the optimal effort expressions and the objective function of the principal we obtain the results stated in lemma 2.

Lemma 2: The optimal solution to the joint moral hazard and adverse selection problem is characterized by

$$e_{1g}^* = \frac{\beta_1^3}{k_g (\beta_1^2 + \beta_2^2)}$$

$$e_{2g}^* = \frac{\beta_1^2 \beta_2}{k_g (\beta_1^2 + \beta_2^2)}$$

$$e_{1b}^* = \frac{v_b^* \beta_1}{k_b}$$

$$e_{2b}^* = \frac{v_b^* \alpha \beta_2}{k_b}$$

[8] See, e.g., Laffont and Martimort (2002), p.42.

[9] See the proof of lemma 2 in the appendix.

$$\mathrm{E}\Pi^{IIS*} = \frac{\beta_1^4[\beta_1^2(k_g^2 + (\Delta - k_g)k_g p + \Delta^2 p^2) + \beta_2^2(k_g^2(1-p)^2 + \alpha^2 k_g(\Delta + k_g)(1-2p)p + (\Delta + k_g)^2 p^2)]}{2(\beta_1^2 + \beta_2^2)k_g(k_g + \Delta)[\beta_1^2(k_g(1-2p) + (\Delta + k_g)p) + \beta_2^2((\Delta + k_g)p + \alpha^2 k_g(1-2p))]}$$

Proposition 2:

(i) The principal's payoff $\mathrm{E}\Pi^{IIS*}$ and the optimal incentive rate v_b^* increase in α if the good state is more likely than the bad state, $p > 0.5$, and decrease in α for $p < 0.5$.

(ii) The larger the difference in disutility related to the good and bad environment reflected in Δ, the lower $\mathrm{E}\Pi^{IIS*}$.

With an IIS in place, the principal faces an adverse selection problem on top of the congruity problem already present in the absence of an IIS.

Analyzing the solutions derived above, it is important to note that optimal incentive rates differ depending on the state. Precisely, $v_g^* > v_b^*$ holds.[10] In fact, the incentive rate chosen in the good state equals the rate optimally chosen in the absence of an adverse selection problem. Incentives in the bad state, in contrast, are downward distorted in order to optimally trade off effort motivation in the bad state and rent payments in the good state. Both results are basically standard results for adverse selection problems and are well known from previous literature.

Beyond that, however, we observe from proposition 2 (i), that v_b^* either increases or decreases in α depending on the probabilities of the states to occur.

To understand this finding, recall that α affects the effectivity of window dressing effort in the bad state. If α is low, window dressing is "expensive" for the agent relative to productive effort. Similar to our previous setting a reduction in α thus reduces the congruity problem and increases equilibrium incentives.

However, as α affects the bad state only, a low α also increases incentives of the agent in the good state to pretend that the bad state is present. As a consequence, higher rent payments are necessary to ensure that self-selection happens in the good state. Accordingly, a decrease in α aggravates the adverse selection problem the principal faces.

Whether this trade-off results in an increase or decrease of v_b^* in α in equilibrium depends on the likelihood of the states. If the good state is more likely, rent payments need to be made frequently. The principal's equilibrium reaction to increased imitation incentives arising from a decrease in α is reducing v_b^*. In contrast, if the bad state is more likely to occur, rent payments rarely happen and the principal optimally increases v_b^* in α, in order to motivate additional productive effort in equilibrium.

Put another way, a decrease in α reduces the congruity problem but at the same time aggravates the adverse selection problem. Which effect is stronger, depends on whether the good or the bad state is more likely. If the bad state is more likely it pays off for the principal to increase incentives to react to

[10] Note that it is straightforward to show that $v_g^* > v_b^*$ holds, whenever $\alpha \in (\alpha^{min}, 1)$ as defined above.

the reduced incongruity. If the good state is more likely, it is optimal to reduce incentives in the bad state further, in order to keep rent payments at bay.

The trade-off between congruity problem and adverse selection problem carries over to the principal's payoff function $E\Pi^{IIS*}$. From proposition 2 (i) we observe that $E\Pi^{IIS*}$ increases (decreases) in α if $p > (<) 0.5$ as well.

It follows that a stronger restriction on window dressing increases the principal's payoff only if the bad state is more likely than the good state, that is only if the adverse selection problem is not too severe. Conversely, the lowest possible restriction on window dressing, tantamount to a large α, pays off, if the good state is more likely, rendering the adverse selection problem dominant.

An increase in the state dependent difference in disutility, reflected in an increase in Δ, reduces the principal's payoff according to proposition 2 (ii). Even though this result carries over from section 4, the reasoning is different. Given that the agent learns the state and self-selects into a truth revealing contract, agency costs increase in Δ as the adverse selection problem becomes harder. The more distinct the state dependent disutility, the larger the incentive of the agent to imitate the bad state if the good one is present. Accordingly, the principal (further) reduces incentives in the bad state in order to keep rent payments at bay in equilibrium. Thus, it is not the agent's inability to condition effort on the state as in section 4, but the more pronounced rent and incentive trade-off, that reduces $\mathrm{E}\Pi^{IIS*}$.

6. IIS implementation choice

Having derived optimal contracts in the absence and the presence of an IIS it remains to investigate under which circumstances it is advisable for a firm to implement an IIS.

In a first step we assume that some accounting system is given and its tightness is reflected in some $\alpha \in (\alpha^{min}, 1)$. If that is the case, the principal's choice depends on the extent the disutility differs in the good state as opposed to the bad one, that is $\Delta = k_b - k_g$. This is stated in proposition 3.

Proposition 3:

> There exists a unique $\Delta^c(\alpha)$ for which $\mathrm{E}\Pi^{0*} = \mathrm{E}\Pi^{IIS*}$ holds. Whenever $\Delta < \Delta^C(\alpha)$ holds, the principal prefers not to implement an IIS. For $\Delta > \Delta^C(\alpha)$ implementation of an IIS is preferable.

It follows that a firm prefers to implement an IIS if and only if the state dependent disutility difference is sufficiently large. To get the intuition, recall that, no matter whether an IIS is present or not, the principal's payoff decreases in Δ. In the absence of an IIS, this results from a lack of managerial effort control. If an IIS is present, the reason is the more pronounced adverse selection problem. The strength of both effects, however, differs depending on the range of Δ. As long as the difference in states is moderate, losses from imprecise effort choices are smaller than losses from trading off incentives and rent payments. It follows that $\mathrm{E}\Pi^{0*} > \mathrm{E}\Pi^{IIS*}$. For an upper range of Δs, the opposite is the case.

We illustrate the effect of Δ on the principal's payoff for a numerical example in figure 1 below.

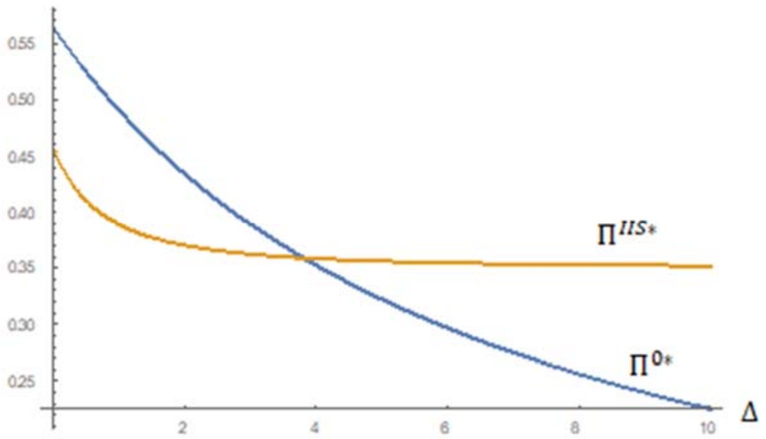

Figure 1 : Optimal payoffs in the presence and absence of an IIS as a function of Δ. Parameter values assumed: $\beta_1 = 2$, $\beta_2 = 2$, $k_g = 2$, $p = 0.7$, $\alpha = 0.6$.

In a next step it remains to analyze to what extent the IIS implementation choice depends on the tightness of accounting standards reflected in α.

Insights are provided in proposition 4.

Proposition 4:

If financial reporting standards are more (less) restrictive, the range of Δs for which implementation of an IIS is unfavorable increases (decreases) as $\frac{d\Delta^c}{d\alpha} < 0$.

As presented in proposition 4 a decrease in α, tantamout to a more restrictive accounting system, moves the critical Δ to the right. Therefore, the range of Δs in which the firm is not interested in implementing an IIS increases if α decreases and v.v. The underlying reason is quite straightforward. In the absence of an IIS a decrease in α reduces the congruity problem and increases the principal's payoff. With an IIS in place, in contrast, the principal faces a trade-off as a lower α reduces the congruity problem but increases the adverse selection problem. It follows that the benefit from reducing α is stronger without an IIS and thus the principal refrains from implementing an IIS for a larger range of Δs, the lower α.

6. Interdependence of IIS implementation and accounting system choice: an example

The easiest way to illustrate how the above analysis results in an interdependency between both choices is via a numerical example.

We assume that the following parameter values hold:

$\beta_1 = 2, \beta_2 = 2 , k_g = 2, p = 0.7, \Delta = 4.$

We distinguish three different sets of accounting standards. They are supposed to reflect possible options a firm faces with regard to accounting standard choice in an economy. The respective sets differ in their tightness reflected in α. Set A is the most restrictive one, B is less restrictive, C the one where earnings management is most efficient. We obtain the following optimal payoff function values for the principal in the presence and absence of an IIS:

Set of standards	A (α= 0.4)	B (α= 0.6)	C (α= 0.8)
$\mathrm{E}\Pi^{IIS*}$	0.3580	0.3582	0.3584
$\mathrm{E}\Pi^{0*}$	0.3737	0.3522	0.3318

Table 1: Optimal payoffs depending on IIS choice and accounting system restrictiveness.

Interpreting the numbers from table 1, we can derive the following statements with regard to the interplay of accounting system choice and the choice to implement an IIS in different settings.

(i) If an IIS is present, the least restrictive accounting system C is preferred.

(ii) If an IIS is absent, the most restrictive accounting system A is preferred.

(iii) If the only accounting system available is C (the least restrictive one), the firm prefers to implement an IIS

(iv) If the only accounting system available is A (the most restrictive one), the firm prefers not to implement an IIS.

(v) If the firm can choose between two accounting systems B and C, it is optimal for the firm to implement an IIS and to choose the least restrictive accounting system C.

(vi) If two accounting systems A and B can be chosen from, the firm optimally refrains from implementing an IIS and chooses the most restrictive accounting system A.

(vii) If all three accounting systems are available, it is optimal to choose the most restrictive one, A, along with no IIS.

Obviously, both choices are not separable and have to be made simultaneously in our example. In the presence of an IIS a firm may find it optimal to choose an accounting system that would not be chosen in the absence of an IIS. At the same time the presence of a particular accounting system affects the choice of implementing an IIS.

9. Conclusion

In this paper we analyze, to what extent the choices of internal and external information systems are interrelated. We assume that an internal information system facilitates a manager's decision-making process but at the same time increases information asymmetry between principal and agent. The external information system, tantamount to the financial reporting system in place, is informative about the agent's efforts. It generates a performance measure used for incentive contracting. Throughout the paper, we interpret the performance measure simply as accounting income. Along with that, the sensitivity of the performance measure towards window dressing effort, reflected in α in our model, is interpreted as a result of the tightness of a set of accounting standards applied. Alternative interpretations are certainly feasible. We could e.g. perceive α as a parameter that reflects the strength of the firm's corporate governance system or even the "quality" of the audit firm hired. Even a combination of all of these aspects could be assumed to eventually determine the effectiveness of the agent's window dressing efforts.

In the absence of an IIS, the only principal-agent problem present is a congruity problem. Once an IIS is implemented, however, an adverse selection problem arises on top of the congruity problem. Thus, the choice to implement an IIS boils down to the question, whether a pure moral hazard problem is preferable to a combined moral hazard and adverse selection problem.

As can probably be expected from previous literature, no IIS is preferred as long as the two types of agents are not too different. Any increase in that difference, specified as Δ in our model, decreases expected payoff for the principal in both settings. Further, no IIS is preferred for a lower range of Δs and an IIS is favorable beyond. The critical Δ, however, is affected by the set of accounting standards present. We find that a tighter set of accounting standards increases the range of Δs, for which no IIS is implemented by the principal. Intuitively, without an IIS a more rigid accounting system strictly benefits the principal. If an IIS is present, in contrast, he trades off benefits from a reduced congruity problem and costs from a more pronounced adverse selection problem. As a consequence, a more restrictive accounting system renders the choice against an IIS more likely.

Once an IIS has been implemented, the principal prefers either the least or the most restrictive set of accounting standards, depending on the probability of the good and bad state to be present. In the absence of an IIS, in contrast, the tightest financial reporting system is always optimal.

It follows, that IIS and external information system choices are not separable and thus need to be made simultaneously in order to ensure that the payoff for the principal is maximized. While this is not a problem in our one shot game, it might be critical in corporate reality. Both choices are rather long term in nature and implementation of either system is costly and time consuming. Besides, in our model we consider the tightness of a set of accounting standards as constant over time once the firm has decided on the set of standards to be applied. Realistically, we need to acknowledge that the tightness of standards might change over time. Standard setters release new or adapted standards all the time. Changes in standards also affect accounting discretion and the scope for earnings management. It follows that, even when the firm sticks to a certain type of financial reporting standards, conceptual changes in the standards result in the need to adapt the IIS over time. In such a setting, simultaneous choices are obviously impossible and the firm needs to adapt the IIS to a changing financial reporting system.

10. Literature

Arya, A., Glover, J., Sunder, S. (1998) Earnings Management and the Revelation Principle, Review of Accounting Studies, 3, (1-2), 7-34.

Baiman, S., Evans, J. (1983) Pre-decision information and participative management control systems, Journal of Accounting Research 21(2), 371-395.

Beyer, A., Guttman, I., Marinovic, I. (2014) Optimal Contracts with Performance Manipulation, Journal of Accounting Research, 52 (4), 817-847.

Chen, H., Leng, F. (2004) Pay-performance sensitivity in a heterogeneous managerial labor market, Journal of Management Accounting Research, Vol. 16, 19-33.

Christensen, J. (1981) Communication in agencies, Bell Journal of Economics 12 (2), 661-674.

Demski, J. (1998) Performance Measure Manipulation, Contemporary Accounting Review 15, 261-285.

Dye, R. (1988) Earnings Management in an Overlapping Generations Model, Journal of Accounting Research 26, 195-235.

Ewert, R., Wagenhofer, A. (2005) Economic Effects of Tightening Accounting Standards to Restrict Earnings Management, The Accounting Review 80 (4), 1101-1124.

Feltham, G., Xie, J. (1994) Performance Measure Congruity and Diversity in Multi-Task Principal/Agent Relations, The Accounting Review 69 (3), 429-453.

Göx, R., Michaeli, B. (2019) Bayesian persuasion, incentive contracting, and performance manipulation, working paper.

Goldmann, E., Slezak, S. (2006) An Equilibrium Model of Incentive Contracts in the Presence of Information Manipulation, Journal of Financial Economics, 603-626.

Grossmann, S. Hart, O. (1983) An Analysis of the Principal-Agent Problem, Econometrica 51, 7-45.

Holmström, B. (1979) Moral Hazard and Observability, The Bell Journal of Economics 10, 74-91.

Holmström, B., Milgrom, P. (1991) Multitask Principal-Agent Analyses: Incentive Contracts, Asset Ownership, and Job Design, Journal of Law, Economics and Organization 7, 24-52.

Laffont, J., Martimort, D. (2002) The Theory of Incentives, Princeton University Press.

Laffont, J., Tirole, J. (1993) A Theory of Incentives in Procurement and Regulation, Massachusetts Institute of Technology.

Liang, P. (2004) Equilibrium Earnings Management, Incentive Contracts, and Accounting Standards, Contemporary Accounting Research, Vol. 21 (3), 685-717.

Marinovic, I., Povel, P. (2017) Competition for Talent under Performance Manipulation, Journal of Accounting and Economics 64 (1), 1-14.

Melumad, N., Reichelstein, S. (1989) Value of Communication in Agencies, Journal of Economic Theory 47, 334-368.

Nafziger, Julia (2009) Timing of information in agency problems with hidden action, Journal of Mathematical Economics 45, 751-766.

Rajan, M., Saouma, R. (2006) Optimal Information Asymmetry, The Accounting Review, 81 (3), 677-712.

Sappington, D. (1984) Incentive Contracting with Asymmetric and Imperfect Precontractual Knowledge, Journal of Economic Theory, 52-70.

Appendix

Proof of lemma 1:

As the participation constraint is binding at the optimum, the principal's optimization problem can be reformulated to obtain the following unconstrained problem:

$$\max_{v,f} \Pi^0 = \beta_1 e_1 - E\left(C\left(e_j\right)\right)$$

$$= \beta_1 \frac{v\beta_1}{\bar{k}} - \frac{\bar{k}}{2}[(\frac{v\beta_1}{\bar{k}})^2 + (\frac{v\beta_2(p+(1-p)\alpha)}{\bar{k}})^2]$$

Optimizing w.r.t. v we obtain $v^* = \frac{\beta_1^2}{\beta_1^2+\beta_2^2(p+(1-p)\alpha)^2}$.

Inserting v^* into the expressions for e_1, e_2, and Π^0, we get the results shown in lemma 1.

□

Proof of proposition 1:

(i)

$$\frac{dv^*}{d\alpha} = -\frac{2\beta_1^2\beta_2^2(1-p)(\alpha(1-p)+p)}{(\beta_1^2+\beta_2^2(\alpha(1-p)+p)^2)^2} < 0$$

$$\frac{d\Pi^{0*}}{d\alpha} = -\frac{\beta_1^4\beta_2^2(\alpha(1-p)+p)(1-p)}{(k_g+\Delta(1-p))(\beta_1^2+\beta_2^2(\alpha(1-p)+p)^2)^2} < 0$$

(ii)

$$\frac{d\Pi^{0*}}{d\Delta} = -\frac{\beta_1^4(1-p)}{2(\Delta(1-p)+k_g)^2(\beta_1^2+\beta_2^2(\alpha(1-p)+p)^2)} < 0$$

□

Proof of lemma 2:

Given that constraints (2) and (3) are binding in the optimum as described above, the principal's optimization problem becomes

$$\max_{f_g,v_g,f_b,v_b} \Pi^{IIS} = p[\beta_1 e_{1g} - s_g(y)] + (1-p)[\beta_1 e_{1b} - s_b(y)]$$

s.t.

$$f_b + v_b(\beta_1 e_{1b} + \alpha\beta_2 e_{2b}) - \frac{k_b}{2}\left(e_{1b}^2 + e_{2b}^2\right) = 0 \tag{2}$$

$$f_g + v_g\left(\beta_1 e_{1g} + \beta_2 e_{2g}\right) - \frac{k_g}{2}\left(e_{1g}^2 + e_{2g}^2\right) =$$

$$f_b + v_b(\beta_1 \frac{v_b\beta_1}{k_g} + \beta_2 \frac{v_b\beta_2}{k_g}) \ - \frac{k_g}{2}((\frac{v_b\beta_1}{k_g})^2 + (\frac{v_b\beta_2}{k_g})^2) \tag{3}$$

$$e_{1g} = \frac{v_g\beta_1}{k_g}$$

$$e_{2g} = \frac{v_g\beta_2}{k_g}$$

$$e_{1b} = \frac{v_b\beta_1}{k_b}$$

$$e_{2b}^* = \frac{v_b\alpha\beta_2}{k_b}.$$

Inserting (2), (3), and the respective expressions for $e_{i,j}$ into the objective function we obtain:

$$\begin{aligned}\max_{f_g,v_g,f_b,v_b} \Pi^{IIS} = p[\beta_1 \frac{v_g\beta_1}{k_g} - [\frac{k_g}{2}\left((\frac{v_g\beta_1}{k_g})^2 + (\frac{v_g\beta_2}{k_g})^2)\right) + \frac{k_b}{2}\left((\frac{v_b\beta_1}{k_b})^2 + (\frac{v_b\alpha\beta_2}{k_b})^2)\right) \\ - v_b\left(\beta_1 \frac{v_b\beta_1}{k_b} + \alpha\beta_2 \frac{v_b\alpha\beta_2}{k_b}\right) + v_b\left(\beta_1 \frac{v_b\beta_1}{k_g} + \alpha\beta_2 \frac{v_b\beta_2}{k_g}\right) \\ - \frac{k_g}{2}\left((\frac{v_b\beta_1}{k_g})^2 + (\frac{v_b\beta_2}{k_g})^2)\right)]] + (1-p)[\beta_1 \frac{v_b\beta_1}{k_b} - \frac{k_b}{2}\left((\frac{v_b\beta_1}{k_b})^2 + (\frac{v_b\alpha\beta_2}{k_b})^2)\right)]\end{aligned}$$

Optimizing w.r.t. v_g and v_b we get

$$v_g^* = \frac{\beta_1^2}{\beta_1^2 + \beta_2^2}$$

$$v_b^* = \frac{\beta_1^2 k_g(1-p)}{\beta_1^2[\ k_g(1-p) + \Delta p] + \beta_2^2[\left(k_g + \Delta\right)p + \alpha^2 k_g(1-2p)]}.$$

Inserting these expressions into the objective function Π^{IIS} above and the respective $e_{i,j}$ we obtain the results presented in lemma 2.

It remains to be shown that (1) and (4) are indeed non-binding given our optimal solutions.

Inserting into (1) we get

$f_g^* + v_g^*\left(\beta_1 e_{1g}^* + \beta_2 e_{2g}^*\right) - \frac{k_g}{2}\left(e_{1g}^{*2} + e_{2g}^{*2}\right) = \frac{v_g^{*2}\beta_2^2}{2k_g} - \frac{v_g^{*2}\beta_2^2\alpha(2-\alpha)}{2(k_g+\Delta)}$.

Thus we require $\frac{v_g^{*2}\beta_2^2}{2k_g} > \frac{v_g^{*2}\beta_2^2\alpha(2-\alpha)}{2(k_g+\Delta)} \Leftrightarrow 1 > \alpha(2-\alpha)$ which holds $\forall\ \alpha \in \left(\alpha^{min}, 1\right)$.

Inserting into (4) we obtain

$$f_b^* + v_b^*(\beta_1 e_{1b}^* + \alpha\beta_2 e_{2b}^*) - \frac{k_b}{2}\left(e_{1b}^{*2} + e_{2b}^{*2}\right) = 0 >$$

$f_g^* + v_g^*\left(\beta_1 \frac{v_g^*\beta_1}{k_b} + \beta_2 \frac{v_g^*\alpha\beta_2}{k_b}\right) - \frac{k_b}{2}\left(\left(\frac{v_g^*\beta_1}{k_b}\right)^2 + \left(\frac{v_g^*\alpha\beta_2}{k_b}\right)^2\right)$

$$\Leftrightarrow 0 > \frac{v_g^* - v_b^*}{2\left(k_g + \Delta\right)}\left(\beta_1^2 + \beta_2^2\alpha(2-\alpha)\right) - \frac{v_g^* - v_b^*}{2k_g}\left(\beta_1^2 + \beta_2^2\right)$$

$$\Leftrightarrow \frac{v_g^* - v_b^*}{2k_g}\left(\beta_1^2 + \beta_2^2\right) > \frac{v_g^* - v_b^*}{2(k_g+\Delta)}\left(\beta_1^2 + \beta_2^2\alpha(2-\alpha)\right). \qquad \text{(A1)}$$

As $(\beta_1^2 + \beta_2^2) > \left(\beta_1^2 + \beta_2^2\alpha(2-\alpha)\right)$ and for $\alpha \in \left(\alpha^{min}, 1\right)$ and $\alpha^{min} = \max\{0, \sqrt{\frac{\beta_2^2 k_g(1-2p) - \Delta p(\beta_1^2+\beta_2^2)}{\beta_2^2 k_g(1-2p)}}\}$, it holds that $v_g^* > v_b^*$, it follows that A1 is satisfied.

□

Proof of proposition 2:

(i) Taking the first derivative of Π^{IIS*} w.r.t. α we get

$\frac{d\Pi^{IIS*}}{d\alpha} = \frac{\alpha\beta_1^4\beta_2^2k_g^2(1-p)^2(2p-1)}{(\Delta+k_g)\left([\beta_1^2(k_g(1-p)+p\Delta)+\beta_2^2((\Delta+k_g)p+\alpha^2k_g(1-2p))\right]^2}$,

which is positive (negative) for $p > (<) 0.5$.

Taking the first derivative of v^* w.r.t. α we get

$$\frac{dv^*}{d\alpha} = \frac{2\alpha\beta_1^2\beta_2^2k_g^2(1-p)(2p-1)}{[\beta_1^2\left[\left(\Delta+k_g\right)p - k_g(2p-1)\right] + \beta_2^2\left[\left(\Delta+k_g\right)p - \alpha^2k_g(2p-1)\right]]^2}$$

which is positive (negative) for $p > (<) 0.5$.

(ii)

$$\frac{d\Pi^{IIS}}{d\Delta} = -\frac{\beta_1^4k_g(1-p)^2[\beta_1^2\left(k_g+2\Delta p\right) + \beta_2^2\left(2\left(\Delta+k_g\right)p + \alpha^2k_g(1-2p)\right)]}{2(\Delta+k_g)^2[\beta_1^2\left(k_g(1-p)+\Delta p\right) + \beta_2^2\left(\left(\Delta+k_g\right)p + \alpha^2k_g(1-2p)\right)]^2} < 0$$

To see the latter, note that the final term in brackets in the numerator can be rephrased as follows:

$$2(\Delta + k_g)p + \alpha^2 k_g(1-2p) = 2\Delta p + \alpha^2 k_g + 2pk_g(1-\alpha^2) > 0$$

□

Proof of Proposition 3:

The proof proceeds as follows:

a) We show that no IIS is preferred, when $\Delta \to 0$ and an IIS is preferred, when $\Delta \to \infty$.

Define $\Pi^{0*} - \Pi^{IIS*} = D\Pi$.

$$\lim_{\Delta\to 0} D\Pi = \frac{(1-\alpha)\beta_1^4\beta_2^2(1-p)p[\beta_2^2(1+\alpha(-1+\alpha+\alpha^2)) + \beta_1^2(2-p+\alpha p) + \beta_2^2 p(1-\alpha)(2p+4\alpha-3\alpha^2+2p\alpha^2)]}{2(\beta_1^2\beta_2^2)k_g[\beta_1^2+\beta_2^2(\alpha(1-p)+p)^2][\beta_1^2(1-p)+\beta_2^2(p(1-\alpha^2)+\alpha^2(1-p))]}$$

>0

$$\lim_{\Delta\to\infty} D\Pi = -\frac{\beta_1^4 p}{2(\beta_1^2+\beta_2^2)k_g} < 0.$$

This shows that there is a lower range of Δs for which no IIS is preferred and an upper range for which IIS is preferred. There has to be at least one Δ^c for which $D\Pi = 0$.

b) We show that only a single Δ^c exists.

We know that $\frac{d\Pi^{0*}}{d\Delta} < 0$ and $\frac{d\Pi^{IIS}}{d\Delta} < 0$ from propositions 1 and 2.

Considering second derivatives we find

$$\frac{dd\Pi^{0*}}{dd\Delta} = \frac{\beta_1^4(1-p)^2}{(k_g+\Delta(1-p))^3(\beta_1^2+\beta_2^2(\alpha(1-p)+p)^2)} > 0$$

$$\frac{dd\Pi^{IIS*}}{dd\Delta} = \frac{\beta_1^4(1-p)^2(\beta_2^4 A + \beta_1^2\beta_2^2 B + \beta_1^4 C)}{(\Delta+k_g)^3[\beta_1^2(k_g(1-p)+\Delta p) + \beta_2^2(\Delta p + k_g p(1-\alpha^2) + \alpha^2 k_g(1-p))]^3}$$

with

$$A = \alpha^4 k_g^2(1-2p)^2 + 3\alpha^2 k_g(\Delta+k_g)p(1-p) + 3p^2[\Delta^2 + \Delta k_g(2-\alpha^2) + k_g^2(1-\alpha^2)]$$

$$B = (2\alpha^2 k_g^2 + 3\alpha^2 k_g\Delta p)(1-p) + 3k_g^2 p(1-\alpha^2) + 3\Delta k_g p(1-\alpha^2 p) + 2p^2\alpha^2 k_g + 6\Delta^2 p^2$$

$$C = 3\Delta k_g p + 3\Delta^2 p^2 + k_g^2(1-p+p^2)$$

Note that the denominator is positive and so are A, B, and C, so that $\frac{dd\Pi^{IIS*}}{dd\Delta} > 0$.

Thus, for any $\Delta > 0$, both payoff functions are decreasing in Δ at a decreasing rate. It follows directly that a single Δ^c only exists in the admissible range.

□

Proposition 4:

Note that there exists a single Δ^c as shown in proposition 3. To show that Δ^c decreases in α it suffices to show that $\frac{dD\Pi}{d\alpha} < 0$. If the difference in payoffs decreases in α for any given Δ, then $D\Pi(\Delta) = 0$ is obtained for a lower Δ the higher α and thus $\frac{dD\Pi}{d\alpha} < 0$ implies $\frac{d\Delta^c}{d\alpha} < 0$.

We continue to show that $\frac{dD\Pi}{d\alpha} < 0$ holds.

$$\frac{dD\Pi}{d\alpha} = \beta_1^4\beta_2^2[\frac{\alpha k_g^2(1-p)^2(1-2p)}{(\Delta + k_g)[\beta_1^2(k_g(1-p)+\Delta p) + \beta_2^2\left((\Delta + k_g)p + \alpha^2 k_g(1-2p)\right)]^2}$$
$$-\frac{(1-p)(\alpha(1-p)+p)}{\left(k_g + \Delta(1-p)\right)[\beta_1^2 + \beta_2^2(\alpha(1-p)+p)^2]^2}]$$

$\frac{dD\Pi}{d\alpha} < 0$ holds if

$$\frac{\alpha k_g^2(1-p)^2(1-2p)}{(\Delta + k_g)[\beta_1^2(k_g(1-p)+\Delta p) + \beta_2^2\left((\Delta + k_g)p + \alpha^2 k_g(1-2p)\right)]^2} - \frac{(1-p)(\alpha(1-p)+p)}{\left(k_g + \Delta(1-p)\right)[\beta_1^2 + \beta_2^2(\alpha(1-p)+p)^2]^2} < 0 \text{ holds.}$$

The above condition can be rephrased to obtain:

$$\left(\Delta + k_g - \Delta p\right)\left(\alpha(1-p) - 2p\alpha(1-p)\right)[k_g\beta_1^2 + k_g\beta_2^2(\alpha(1-p)+p)^2]^2$$
$$<$$
$$\left(\Delta + k_g\right)(\alpha(1-p)+p)\left[\beta_1^2(k_g(1-p)+\Delta p) + \beta_2^2\left(k_g p + \Delta p + \alpha^2 k_g(1-2p)\right)\right]^2$$

Comparing the first two terms in brackets with $p > 0$ we observe:

$\left(\Delta + k_g - \Delta p\right) \le \left(\Delta + k_g\right)$ and $\left(\alpha(1-p) - 2p\alpha(1-p)\right) < (\alpha(1-p)+p)$.

In order to show that the l.h.s is smaller than the r.h.s of the inequality, it remains to show that the remaining term is smaller in the l.h.s. than in the r.h.s.:

$$k_g\beta_1^2 + k_g\beta_2^2(\alpha(1-p)+p)^2 < \beta_1^2(k_g(1-p)+\Delta p) + \beta_2^2\left(k_g p + \Delta p + \alpha^2 k_g(1-2p)\right)$$

Note that the r.h.s. is increasing in Δ while the l.h.s is not. Both terms are increasing in α but the l.h.s. increases at a higher rate. It follows that if there is a parameter combination in which the above inequality is violated, it should be at $\Delta \to 0$ and $\alpha \to 1$.

However, taking the limit w.r.t. both parameters, we obtain:

$$\lim_{\Delta \to 0, \alpha \to 1} \frac{dD\Pi}{d\alpha} = -\frac{\beta_1^4 \beta_2^2 p}{(\beta_1^2 + \beta_2^2) k_g} < 0.$$

It follows that for any combination of parameter values within the admissible range $\frac{dD\Pi}{d\alpha} < 0$ holds and thus $\frac{d\Delta^c}{d\alpha} < 0$.

$\square$

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