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Early versus late accounting information in a limited commitment setting

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Abstract

We consider a two period principal-agent problem in a LEN setting. Stock prices as well as accounting measures are available for incentive contracting. The principal needs to implement one out of two accounting systems. While the early accounting information system reports an accounting signal in the period it is produced, the late accounting system reports this information with one period delay. As accounting information is considered contractible if and only if it is reported within the two period horizon of the game, the late system ends up providing less contractible information than the early one. Accounting information is supposed to be effort informative and value relevant. Stock prices reflect all value relevant information. This includes accounting information along with further information that is value relevant but not effort informative. We derive optimal compensation contracts in a full committment setting and in a limited commitment setting for both, the early and the late accounting information system. With full commitment the early system dominates the late one. If the early system is implemented stock prices are not used for contracting at all. In contrast, if the late system is present, stock prices are required to incentivice second period effort at all. However, contracting on them results in an inferior risk-incentive trade-off as compared to contracting on early accounting information only. With limited commitment implementing the late accounting information system may benefit the principal. If accounting signals are positively correlated, limited commitment causes excessive second period incentive rates. Using the late system in combination with stock prices serves as a committment device. Noise immanent in the stock prices reduces optimal incentive rates and thus counteracts the over-incentives. Second period benefits may more than outweigh the cost related to using stock prices in the first period.

1 Introduction

The overall objective of financial statements is to give a fair presentation of the state and performance of an entity in order to facilitate economic decisions of its users. To clarify and operationalize this objective, standard setters have established several principles that guide standard setting as well as application of standards. Two key concepts everything else is basically derived from are relevance and reliability. Reliability requires e.g. faithful representation and verifiability. Relevance implies materiality and timeliness. The tension is obvious. E.g. information is supposed to be most relevant if it is current forward looking information. Such information, however, is typically hard to verify e.g. via an audit. It follows that standard setters need to decide upon how to balance these conflicting principles. Emphasizing either relevance or reliability when deciding whether to include some information into financial statements is tantamount to choosing a certain degree of conservatism. A similar decision possibly needs to be made on a firm level, too. E.g. firms may have some leeway with regard to which set of accounting standards they want to apply. Alternatively, they can opt to exercise a certain degree of accounting discretion in more or less conservative fashion.

In this paper we analyze costs and benefits of conservatism from a contracting perspective. Conservatism in our model translates into delayed reporting of the information, emphasizing verifiability of the information at the cost of timeliness. We consider a two period principal-agent relationship. The agent performs an effort in both periods and the principal aims at providing incentives via an appropriate compensation contract.

We consider two different types of accounting or reporting systems. Both systems produce identical information at the end of each period. Signals are value relevant and informative with respect to the agent's effort. The first system reports accounting information immediately, that is in the period it is produced. The second system is conservative and reports each signal with one period delay. In what follows we denote the former system the early information system and the latter the late or conservative information system. Reporting is a necessary precondition for contractibility in our setting as it ensures information is not only observable but verifiable by a third party. Beyond that, delay of reporting critically affects contractibility. To see that consider a signal that is reported sometimes after the agent has left the firm in a distant future. Such a signal becomes practically uncontractible as waiting for its realization is unsuitable. We reflect this aspect in our model by assuming that information is contractible only if it becomes observable and verifiable within the two period horizon of our game. Thus the direct effect of late information in the model is less contractible information. With the late accounting information system in place the second period accounting signal becomes unavailable for contracting, as it will not be reported throughout the game. Thus the second accounting system in fact is one that provides a reduced set of performance measures for contracting as compared to the early information system.[1]

Importantly, accounting information is typically not the only source of information available for valuation as well as for contracting purposes. Moreover, previous contributions to the literature have shown that the presence or absence of other information sources is critical for the value of accounting information.[2] In order to account for this issue and to reflect empirical observations with regard to compensation contracts, we assume that stock prices are available for contracting besides accounting measures at the end of each period. Stock prices in our model reflect all value relevant information available in the market in the sense of strong form efficient markets. This implies that accounting information is reflected in prices as soon as it is produced no matter if it is reported or not. Accordingly, which accounting system is in place does not affect the stock price. Alternatively stated, we assume that once produced, accounting information penetrates the market well before this information is published in financial statements.[3] The role of financial statements in such a setting of course is primarily one of disciplining the reporting process. More important for our model, however, is the fact that reporting renders accounting measures contractible. Besides accounting information, stock prices reflect non-accounting information to the extent that it is value relevant. While we assume accounting information to be action informative we model this additional information to be uninformative with respect to the agent's actions. Thus stock prices as compared to accounting measures turn out to be noisy measures of the agent's effort; something that is very much in line with empirical findings.

Within this structure we contrast a full commitment and a limited commitment setting.

In the full commitment setting the timely accounting system dominates the conservative system. With the early system in place, noisy stock prices would not be used for contracting at all as they are a pure garbling of accounting measures. If the late system is implemented, however, the only way to motivate second period effort is to use the stock price measure in period two. It turns out if the stock price is used in the second period it should be used in period one, too, along with the accounting measure. Doing so allows to hedge some of the additional risk

[1] We consider conservatism and related delayed reporting as the very reason for a reduced set of contractible information. The results derived, however, hold for any two types of accounting systems that provide the principal with different signals to be contracted upon, no matter what causes the unavailablity of a measure in one system.

[2] See e.g. Antle et al. (1994).

[3] The fact that accounting information to a large extent is reflected in market prices before it is published has already be shown in the seminal paper by Ball and Brown (1968).

introduced by using the second period price.

With limited commitment our results differ qualitatively. Restricting our analysis to renegotiation-proof contracts we find that implementing the conservative accounting system benefits the principal in some settings. In fact implementing the early system and abstaining from using stock prices may induce overincentives in period two. This occurs when a positive correlation of accounting signals is present but ignored when ex post optimal second period incentive rates are determined. Implementing the late system in such a setting first of all results in an optimal use of stock prices. This in turn triggers reduced incentive rates due to costly noise immanent in prices. It is in that sense that the late system with limited commitment may serve as a commitment device for the principal to keep second period over-incentives at bay. We show that the second period benefit may even exceed first period costs and result in overall benefits. From a standard setting perspective our results show that a low degree of conservatism and thus an emphasis on relevance rather than reliability benefits contracting for sure with full commitment. With limited commitment there is no dominant set of standards whatsoever.

Our model setup builds on findings from at least two different streams of literature.

The first one is the literature concerned with limited commitment. When long term commitment is infeasible, the equilibrium outcome is determined by sequentially rational contracting decisions. Ex post efficient contracts, however, may well be inefficient from an ex ante perspective. This inefficiency results in a loss in welfare from limited commitment that can be avoided in special cases only (see Fudenberg et al. (1990)). In a two-period LEN-setting Indjejikian and Nanda (1999) and Christensen et al. (2003, 2005) show that limited commitment generally creates a welfare loss if performance measures are inter-temporarily correlated. Their result naturally extends to our paper. Schöndube (2008) compares a long-term contract to a sequence of short-term contracts if verifiable and non-verifiable information is observed by the contracting parties.

Moreover, in a recent paper Schöndube-Pirchegger and Schöndube (2012) show that delegation of decision rights may serve as a commitment to higher powered incentives in an agency with limited commitment. As opposed to that we show in this paper that stock price measures may be used as a commitment to low incentives.

The second stream of literature investigates the optimal aggregation of signals and the simultaneous use of accounting measures and market prices in incentive contracts. Bushman and Indjejikian (1993) analyze a rational expectations model in which both the market price and the accounting income are informative about firm value. In a similar approach Kim and Suh

(1993) investigate optimal incentive contracts based on the market price and on accounting earnings when shareholders are risk averse.[4] Gjesdal (1981) shows that aggregation for stewardship purposes typically differs from aggregation for valuation. Building on that Feltham and Xie (1994) demonstrate that contracting on a market price that aggregates accounting information only, is likely to be inferior to a contract that uses the very same accounting measures directly. The inefficiency of stock prices following from suboptimal information aggregation is further demonstrated in Paul (1992). Our findings in the full commitment setting are very much in line with this literature. With limited commitment, however, we show that the results change qualitatively.

The next section introduces the basic model. Section 3 characterizes optimal compensation contracts with full commitment and section 4 with limited commitment. Section 5 concludes.

2 The model

We consider a two-period LEN-model of repeated moral hazard. At the beginning of the first period the principal hires an agent to perform a certain task a_t in each period $t = 1, 2$. The firm's terminal value is given by

$$x = a_1 + a_2 + \varepsilon_x.$$

ε_x is a normally distributed noise term with zero mean and variance σ_x^2.

As the terminal value x is assumed to be realized some time in the future it is unavailable for contracting. In fact, throughout this paper we generally restrict contractibility to measures that become observable and verifiable within the two period horizon of our game. Potential measures to be contracted upon are either reported accounting measures or stock prices observed in the marked.

We consider two alternative accounting systems. Both systems produce identical information but differ with respect to the timing of reporting. Once a piece of information is reported in the financial statements it becomes contractible. Accounting system 1 reports information immediately when it is produced. As mentioned above we call this system the early accounting information system A_1. It reports some signal y_1 at $t = 1$, and y_2 at $t = 2$. Accounting system A_2 in contrast reports each signal with one period delay. Reporting from both systems is contrasted in figure 1 . The second system is regarded a more conservative accounting system that requires e.g. a higher degree of reliability in order to report a certain type of information. With A_2 signal

[4] See also the discussion by Lambert (1993).

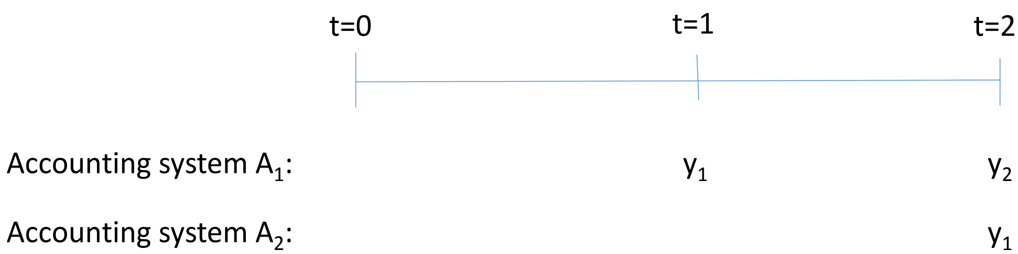

Figure 1: Accounting systems A_1 and A_2

y_2 is reported outside the contracting period and thus cannot be used for contracting anymore.[5] The accounting signals are defined as follows

$$y_1 = a_1 + \varepsilon_1, \quad y_2 = a_2 + \varepsilon_2.$$

y_1 and y_2 depend on the agent's effort in the respective period. $(\varepsilon_1, \varepsilon_2)$ are normally distributed noise terms with mean zero and variance σ^2 . Furthermore we assume that $corr\,(\varepsilon_1, \varepsilon_2) = \lambda$.

The principal implements one of the two accounting systems at $t = 0$. Which one is used is either prescribed by a standard setter, who requires a more or less conservative approach, or it may be subject to the principal's choice. In the latter case we assume that once a reporting system is implemented it cannot be changed throughout the game.

Moreover, the firm's market price is available for contracting. No matter what accounting system is in place, we assume that stock prices immediately reflect all value relevant information available somewhere in the market. Markets in our model are strong form efficient. It follows that the stock price reflects accounting information at the same point in time as system A_1 does. In addition we assume that market prices P_t with $t = 1, 2$ reflect information beyond those produced by the accounting system. We denote this information $w_1 = \varepsilon_{w_1}$ at $t = 1$ and $w_2 = \varepsilon_{w_2}$ at $t = 2$. ε_{w_1} and ε_{w_2} are normally distributed variables with mean zero, variance σ^2, and $corr\,(\varepsilon_{w_1}, \varepsilon_{w_2}) = \mu$. Note that w_1 and w_2 are neither individually contractible nor do they depend on the agent's effort. They are not correlated to the effort-informative measures (y_1, y_2). As such (w_1, w_2) take into account that stock prices reflect information that is informative about firm value but not necessarily about the agent's actions. The market price P_t in our setting equals the expected terminal firm value, conditional on the information available at t

[5] We omit modeling a signal y_0 produced at t=0 and reported at t=1 under A_2. The point is that a signal produced before any effort has been performed could add very little insights to our story.

and conditional on rational conjectures with respect to unobservable actions.[6] Specifically,with $\mathbf{p}_1 = (y_1, w_1)$, $\mathbf{p}_2 = (y_2, w_2)$, $\mathbf{p} = (\mathbf{p}_1, \mathbf{p}_2)$ we obtain

$$\begin{aligned} P_1 &= E\left(x|\mathbf{p}_1, \widehat{\mathbf{a}}\right), \\ P_2 &= E\left(x|\mathbf{p},\widehat{\mathbf{a}}\right) \end{aligned} \tag{1}$$

Finally, we denote the correlation between first-period signals (y_1, w_1) and x by v_1, and between (y_2, w_2) and x by v_2. Thus $\boldsymbol{\varepsilon} = (\varepsilon_1, \varepsilon_{w_1}, \varepsilon_2, \varepsilon_{w_2}, \varepsilon_x)$ has a joint normal distribution with covariance matrix:

$$\underset{(\varepsilon_1,\varepsilon_{w_1},\varepsilon_2,\varepsilon_{w_2},\varepsilon_x)}{\boldsymbol{\Sigma}} = \begin{pmatrix} \sigma^2 & 0 & \lambda\sigma^2 & 0 & v_1\sigma\sigma_x \\ 0 & \sigma^2 & 0 & \mu\sigma^2 & v_1\sigma\sigma_x \\ \lambda\sigma^2 & 0 & \sigma^2 & 0 & v_2\sigma\sigma_x \\ 0 & \mu\sigma^2 & 0 & \sigma^2 & v_2\sigma\sigma_x \\ v_1\sigma\sigma_x & v_1\sigma\sigma_x & v_2\sigma\sigma_x & v_2\sigma\sigma_x & \sigma_x^2 \end{pmatrix}.$$

We require $\boldsymbol{\Sigma}$ to be a positive definite matrix which rules out, e.g., extreme cases like λ or μ equal to -1 or $\sigma = 0$. We can define the following sub-matrices of $\boldsymbol{\Sigma}$ for partitions of $\boldsymbol{\varepsilon}$

$$\begin{aligned} \boldsymbol{\Sigma}_{\mathbf{p}} &= \begin{pmatrix} \sigma^2 & 0 & \lambda\sigma^2 & 0 \\ 0 & \sigma^2 & 0 & \mu\sigma^2 \\ \lambda\sigma^2 & 0 & \sigma^2 & 0 \\ 0 & \mu\sigma^2 & 0 & \sigma^2 \end{pmatrix}, \boldsymbol{\Sigma}_{\mathbf{p}_1} = \begin{pmatrix} \sigma^2 & 0 \\ 0 & \sigma^2 \end{pmatrix} \\ \boldsymbol{\Sigma}_{\mathbf{p},x} &= \begin{pmatrix} v_1\sigma\sigma_x & v_1\sigma\sigma_x & v_2\sigma\sigma_x & v_2\sigma\sigma_x \end{pmatrix}, \boldsymbol{\Sigma}_{\mathbf{p}_1,x} = \begin{pmatrix} v_1\sigma\sigma_x & v_1\sigma\sigma_x \end{pmatrix}, \\ & \boldsymbol{\Sigma}_{\mathbf{p}_2,\mathbf{p}_1} = \begin{pmatrix} \lambda\sigma^2 & 0 \\ 0 & \mu\sigma^2 \end{pmatrix}. \end{aligned}$$

Given that $\boldsymbol{\varepsilon}$ is normally distributed, market prices given in (1) can be written as

$$\begin{aligned} P_1 &= K_1 + \boldsymbol{\beta}_1\mathbf{y}_1 \\ P_2 &= K_2 + \boldsymbol{\beta}_2\mathbf{y}, \end{aligned}$$

where $\boldsymbol{\beta}_1 = \boldsymbol{\Sigma}_{\mathbf{p}_1,x}\boldsymbol{\Sigma}_{\mathbf{p}_1}^{-1}$, $K_1 = E\left(x|\widehat{\mathbf{a}}\right) - \boldsymbol{\Sigma}_{\mathbf{p}_1,x}\boldsymbol{\Sigma}_{\mathbf{p}_1}^{-1}E\left(\mathbf{p}_1|\widehat{\mathbf{a}}\right)$, $\boldsymbol{\beta}_2 = \boldsymbol{\Sigma}_{\mathbf{p},x}\boldsymbol{\Sigma}_{\mathbf{p}}^{-1}$, and $K_2 = E\left(x|\widehat{\mathbf{a}}\right) - \boldsymbol{\Sigma}_{\mathbf{p},x}\boldsymbol{\Sigma}_{\mathbf{p}}^{-1}E\left(\mathbf{p}|\widehat{\mathbf{a}}\right)$, or equivalently,

$$\begin{aligned} P_1 &= K_1 + \beta\left(y_1 + w_1\right), \\ P_2 &= K_2 + \beta_{y_1}y_1 + \beta_{w_1}w_1 + \beta_{y_2}y_2 + \beta_{w_2}w_2, \end{aligned} \tag{2}$$

[6] See, e.g., Paul (1992) and Feltham and Xie (1994).

with $\beta = \frac{\sigma_x}{\sigma} v_1, \beta_{y_1} = \frac{\sigma_x}{\sigma} \frac{\lambda v_2 - v_1}{\lambda^2 - 1}, \beta_{w_1} = \frac{\sigma_x}{\sigma} \frac{\mu v_2 - v_1}{\mu^2 - 1}, \beta_{y_2} = \frac{\sigma_x}{\sigma} \frac{\lambda v_1 - v_2}{\lambda^2 - 1}$, and $\beta_{w_2} = \frac{\sigma_x}{\sigma} \frac{\mu v_1 - v_2}{\mu^2 - 1}$.
To exclude trivial cases we assume parameter settings where all βs are unequal to zero throughout the whole analysis.

The agent is strictly risk averse with utility $U^A = -\exp\left(-r\left(S - C\left(\mathbf{a}\right)\right)\right)$. Here S denotes the agent's compensation, $C\left(\mathbf{a}\right) = \frac{a_1^2 + a_2^2}{2}$ is the agent's personal cost from providing effort $\mathbf{a} = \left(a_1, a_2\right)$, and $r > 0$ is the agent's risk aversion coefficient. We restrict attention to two-period incentive contracts that are linear in the performance measures. This assumption combined with exponential utility and normality leads to the well known LEN-specification. The agent's preferences can be represented by

$$CE\left(S, \mathbf{a}\right) = E\left(S\right) - C\left(\mathbf{a}\right) - \frac{r}{2} Var\left(S\right).$$

We normalize the certainty equivalent of the agent's reservation utility to zero.
The principal is risk neutral. She chooses performance measures and optimal contracting coefficients to maximize her expected net outcome $U = E\left(x - S\right)$.

With respect to the agent's compensation contract, we have to distinguish A_1 and A_2: Under A_1 the compensation contract is defined as

$$S^{A_1} = f + s_1 y_1 + s_2 y_2 + z_1 P_1 + z_2 P_2.$$

Under A_2 the compensation contract becomes

$$S^{A_2} = f + s y_1 + z_1 P_1 + z_2 P_2.$$

Here f denotes a fixed payment and s, s_t and z_t are incentive coefficients. As under A_2 accounting report y_1 is not available before $t = 2$ we denote the (only) bonus coefficient s rather than s_1.

3 Full commitment solutions

In this section we characterize the full commitment setting. Both contracting parties can commit to a long-term two-period contract that cannot be renegotiated after it has been signed. The general optimization problem of the principal under full commitment can be stated as follows with $S \in \left\{S^{A_1}, S^{A_2}\right\}$:

$$\max_S U = E(x - S) \tag{3}$$

s.t.

$$CE(S, \mathbf{a}) \geq 0 \tag{IR}$$

$$\mathbf{a} = \arg\max_{\mathbf{a}'} CE(S, \mathbf{a}'). \tag{IC}$$

The risk neutral principal maximizes her net return subject to two conditions. The individual rationality constraint (IR) is binding at the optimum and ensures that the agent accepts the contract. Further, the agent chooses his actions in order to maximize personal welfare. This is reflected in the incentive compatibility constraint (IC).

We start assuming that the accounting system A_1 has been implemented. Accordingly S^{A_1} as defined above is used.

Lemma 1 *The optimal full commitment incentive contract given the early system A_1 is used contains*

$$\begin{aligned} s_1^* &= s_2^* = \frac{1}{1 + r\sigma^2(1+\lambda)}, z_1^* = 0, z_2^* = 0 \\ U^* &= \frac{1}{1 + r\sigma^2(1+\lambda)}. \end{aligned}$$

Proof. See the Appendix. ■

The key result from Lemma 1 is that market prices are never used for contracting along with A_1. Prices in our setting are a weighted sum of all value relevant measures as stated in (2). As such they are a garbling of the action-informative measures y_1 and y_2 adding unwanted noise only.

With the late accounting information system A_2, however, results are structurally different as is stated in lemma 2 below.

Lemma 2 *The optimal full commitment incentive contract under the conservative system A_2 uses*

$$\begin{aligned} s^{**} &= \frac{r\sigma^2\beta_{w_2}^2\left(\mu^2-1\right) + \beta_{y_2}\left(\beta_{w_2}\mu + \beta_{w_1} + \beta_{y_2} - \beta_{y_1}\right)\left(r\sigma^2(\lambda-1)-1\right)}{N}, \\ z_1^{**} &= -\frac{\beta_{y_2}\left(r\sigma^2(\lambda-1)-1\right)}{N},\ z_2^{**} = -z_1^{**} \\ U^{**} &= \frac{r\sigma^2\left[\beta_{w_2}^2\left(\mu^2-1\right) + 2\beta_{y_2}^2(\lambda-1)\right] - 2\beta_{y_2}^2}{N}. \end{aligned}$$

with $N = r^2\sigma^4\left[\beta_{y_2}^2\left(\lambda^2-1\right) + \beta_{w_2}^2\left(\mu^2-1\right)\right] + r\sigma^2\left[\beta_{w_2}^2\left(\mu^2-1\right) - 2\beta_{y_2}^2\right] - \beta_{y_2}^2.$

Proof. See the Appendix. ■

With y_2 unavailable for contracting the principal has to use the market price P_2 to motivate any positive effort a_2 at all. But if P_2 is included in the contract the non-action-informative measures w_1 and w_2 inevitably become element of the agent's compensation. If solely y_1 (via s) and P_2 are used for contracting, the principal ends up controlling four signals (y_1, y_2, w_1, w_2) using only two incentive coefficients s and z_2. It turns out she can do better by additionally using P_1. Specifically, as P_1 and P_2 are positively correlated, P_1 can be used to hedge some of the risk introduced into the contract by using P_2. The risk minimizing hedge requires z_2 to equal z_1 but with opposite signs. If y_1, P_1, and P_2 are used in the incentive contract the agent chooses his effort equal to (see Proof of Lemma 2 for details)

$$\begin{aligned} a_1 &= s + \beta z_1 + \beta_{y_1} z_2 \\ a_2 &= \beta_{y_2} z_2. \end{aligned} \tag{4}$$

Note that it is always optimal to induce positive effort in the second period. It follows that z_2^{**} is positive if $\beta_{y_2} > 0$ and negative if $\beta_{y_2} < 0$.

Contrasting the principal's expected utility attainable in both settings we obtain proposition 1.

Proposition 1 $U^* - U^{**} = \frac{\beta_{w_2}^2 r\sigma^2(1-\mu)(1+\mu)\left(r\sigma^2(\lambda-1)-1\right)}{2N(1+r\sigma^2(1+\lambda))} > 0.$

Proof. The result follows from subtracting U^* and U^{**}as given in Lemma 1 and Lemma 2 and simplifying. ■

It becomes apparent that using A_1 rather than A_2 strictly benefits the principal in the full commitment setting. With A_1 in place market prices have no role in the manager's incentive contract. Rather, relying on the effort informative signals (y_1, y_2) provides the optimal second-best risk and incentive trade-off. With A_2, in contrast, the principal is forced to use P_2 to create second period effort incentives and thus introduces additional noise into the agent's compensation. Even though some of the noise can be hedged by including P_1, with A_2 the contract remains inferior resulting in higher agency costs and a lower expected outcome U^{**} as compared to U^*.

4 Limited commitment solutions

4.1 Limited commitment and renegotiation-proofness in a two-period LEN-setting

In this section we relax our previous assumption that principal and agent can commit to a long-term (two-period) incentive contract. From now on both parties cannot preclude ex ante to renegotiate an inefficient contract S ex post. S becomes inefficient if the ex post trade-off between risk and incentives that arises after some uncertainty has been resolved differs from the ex ante trade-off. We assume below that the principal is free to offer a revised contract S^R to the agent at the end of the first period. At that stage of the game P_1 and y_1 have been observed and the agent has performed a_1. The agent will accept the new contract if he is at least indifferent between S and S^R. Literally, this kind of renegotiation procedure can take place at any time during the two-period relation. The end of the first-period, however, appears to be most self-evident for the contractual relationship considered here. Typically compensation committees meet annually and adapt managerial compensation at the end of a period.[7]

From previous literature we know that under complete contracts it is not necessary to analyze the renegotiation procedure explicitly. Without loss of generality one can concentrate on initial contracts that are robust against renegotiation (renegotiation-proof).[8] This result also holds in our model.

Christensen et al. (2003) prove the renegotiation-proofness-principle for a two-period LEN-model and show that an initial contract is renegotiation-proof if and only if second-period incentive weights are chosen sequentially optimal. In other words the optimization problem to be considered is identical to the one from the commitment setting except that renegotiation proof second-period incentive rates apply. In what follows we use this approach. We denote the renegotiation-proof values with superscript "^{R}" for renegotiation-proofness.

4.2 The value of market prices and late information under limited commitment

At the beginning of the second period, the agent has already performed first-period action a_1 and P_1 and y_1 have been observed. The principal's ex post problem is to determine sequentially optimal second-period incentive weights. She maximizes the second-period part of her expected

[7] See Christensen et al. (2003).

[8] See Fudenberg and Tirole (1990) and Christensen et al. (2003).

gross output, a_2, net of its cost and subject to the incentive constraint for second-period effort. The cost covers the agent's disutility of performing effort in period 2, $a_2^2/2$, and the posterior risk premium to be paid to the agent. Consider the early accounting information system A_1 first. Assuming that renegotation of the contract is possible at the end of the first period, under A_1 the incentive coefficients s_2 and z_2 of the second period measures y_2 and P_2 have to be chosen sequentially optimal. The principal solves the following problem

$$\begin{aligned} \max_{s_2,z_2} U_2^{A_1} &= a_2 - \frac{a_2^2}{2} - \frac{r}{2} Var\left(s_2 y_2 + z_2 P_2 | y_1, P_1\right) \\ \text{s.t. } a_2 &= s_2 + z_2 \beta_{y_2} \end{aligned}$$

For the late accounting information system A_2 the coefficients s and z_2 must be set sequentially optimal. The corresponding program is given by

$$\begin{aligned} &\max_{s,z_2} U_2^{A_2} = a_2 - \frac{a_2^2}{2} - \frac{r}{2} Var\left(s y_1 + z_2 P_2 | y_1, P_1\right) \\ &\text{s.t. } a_2 = z_2 \beta_{y_2}. \end{aligned}$$

Lemma 3 *a) The renegotiation-proof second-period weights under A_1 are given by*

$$s_2^{R*} = \frac{1}{1 + r\sigma^2\left(1 - \lambda^2\right)} \text{ and } z_2^{R*} = 0.$$

b) The renegotiation-proof second-period weights under A_2 are given by:

$$z_2^{R**} = \frac{\beta_{y_2}}{\beta_{y_2}^2\left(1 + r\sigma^2\left(1-\lambda^2\right)\right) + \beta_{w_2}^2 r\sigma\left(1-\mu^2\right)}.$$

Any value of s is renegotiation proof.

Proof. See the appendix. ■

We observe from lemma 3 that results in the limited commitment setting are structurally equivalent to those in the full commitment case. Under A_1 the action informative measure y_2 is used for contracting while the stock price is not. Under A_2 the market price P_2 is needed to induce second-period effort incentives. Differences occur, however, with respect to the incentive rates applied and the effort induced. With A_1 the agent chooses his effort according to $a_2^{R*} = s_2^{R*}$. Besides, y_1 can be contracted upon ex ante optimal. Under A_2 the agent chooses $a_2^{R,**} = z_2^{R**}\beta_{y_2}$. To be able to compare incentives provided via the different contracts we introduce what we call the "effective incentive rate" with respect to stock price $\overline{z}_2^{R**} = z_2^{R**}\beta_{y_2}$. It denotes the additional variable compensation under A_2 if the agent increases his effort a_2 by one unit.

Lemma 4 *a)Under A_1, the following relations apply:* $s_2^* \gtreqless s_2^{R*}$ *iff* $\lambda \lesseqgtr 0 \Leftrightarrow a_2^* \gtreqless a_2^{R*}$*iff* $\lambda \lesseqgtr 0$.

Proof. See the Appendix. ■

Lemma 5 $\overline{z}_2^{R**} < s_2^{R*}$.

Proof. See the Appendix. ■

Consider the second-period renegotiation-proof incentive coefficient on y_2 under A_1. s_2^{R*} trades-off second-period effort and second-period compensation risk conditional on first period information. As y_2 and y_1 are correlated, s_2^{R*} accounts for the posterior variance $Var\left(y_2|y_1\right) = \sigma^2\left(1-\lambda^2\right)$.

Under A_2 to induce second period effort the principal has to contract upon market price P_2. Thereby, the principal inevitably contracts also on the non-informative signals w_1 and w_2. Again the posterior variance of the agent's compensation matters but now this also comprises $Var\left(w_2|w_1\right) = \sigma^2\left(1-\mu^2\right)$.

Whether second-period renegotiation-proof incentives are too high or too low (or equal) compared to the ex ante efficient ones under A_1 depends on the sign of correlation λ.[9] Importantly, according to lemma 5 ex post efficient second-period (effective) incentives under A_2 are always lower than under A_1. The latter results from the fact that under A_2 the second-period market price will become element of the second-period contract. Similar to the full commitment setting, contracting on the market price is inefficient ex post compared to using y_2 under A_1. The market price must be used under A_2 to induce second-period effort but it includes non-informative signals which comes with a cost to the principal. In order to reduce the costs related to this inefficiency, sequentially optimal second-period effort incentives under A_2 are lower than under A_1 where only the action-informative signal will be contracted upon.

The important point here is that under limited commitment the ex post inefficiency due to market price contracting under A_2 may become efficient from an ex ante perspective. To see this, consider a situation where the principal induces too high second-period effort from the ex ante point of view under A_1. In this case she would be better off if she could credibly commit to a lower second-period incentive rate. Indeed, by installing the late information system A_2, the principal implicitly commits to such lower second-period incentives as she has to use market price

[9] See also Indjejikian and Nanda (1999), Christensen et al. (2005), and Schöndube-Pirchegger and Schöndube (2012) for the impact of correlation in a dynamic agency.

compensation. The positive effect of using non-action-informative measures on second-period renegotiation-proof incentives potentially overcompensates the negative effect on the total risk premium of using a non informative measure. A necessary condition for this effect to arise is provided in the following proposition:

Proposition 2 *A necessary condition for accounting system A_2 to be optimal under limited commitment is $\lambda > 0$.*

Proof. For $\lambda = 0$, $s_2^{R*} = s_2^*$ under A_1 and the full commitment solution will be induced under renegotiation-proofness. Under full commitment, however, as has been shown in Proposition 1, A_1 strictly dominates A_2. If $\lambda < 0$ under A_1 the agent is induced to perform too low second-period effort with renegotiation-proofness. Under A_2 induced effort a_2 is even lower (lemma 4). As the principal's objective function in our LEN-setting is strictly concave, the stronger the deviation from the optimum the lower the corresponding objective function values. Hence, $U^{R*} \geq U^{R**}$ for $\lambda \leq 0$. For $\lambda > 0$ a_2^{R*} is too high compared to a_2^*. Now, A_2 may outperform A_1 as it potentially relaxes the principal's renegotiation-proof constraint. Hence, if $U^{R**} > U^{R*}$ then $\lambda > 0$. ■

If accounting signals y_1 and y_2 are positively correlated, $\lambda > 0$, limited commitment forces the principal to induce too high second-period effort under A_1. To see this, consider the full commitment solution first: If λ is positive, intertemporal persistence effects increase compensation risk and in turn reduce effort incentives in both periods. With limited commitment, however, the principal has to set renegotiation-proof second-period incentives. This includes to choose the second-period incentive rate as if the first-period effort was done and first-period signal y_1 has been already observed. For $\lambda > 0$, y_1 is informative about y_2 which shows up in the posterior variance, $\sigma^2 \left(1 - \lambda^2\right) < \sigma^2$. As ex post efficient incentives are based on the posterior variance $s_2^* < s_2^{R*}$ for $\lambda > 0$. In such a situation, the late information accounting system leads to lower second-period incentives as it has to use the second period market price to control second period effort. As a result, the market price compensation inherent in A_2 may relax the renegotiation-proof constraint relative to A_1. Using A_2 the principal implicitly commits to (relatively) low second-period incentives. This commitment is beneficial if it outweighs the cost of using a non-informative measure for contracting via the market price. Due to the large set of parameters $(r, \sigma, \sigma_x, \lambda, \mu, v_1, v_2)$ included in this model it is difficult to provide robust sufficient conditions for the optimality of A_2 that cover a wide range of parameter constellations. We rather provide a numerical example to add intuition to the above proposition.

Example 1: Parameters of the example: $\sigma = 1.6, \sigma_x = 1, \lambda = 0.76, \mu = -0.9, v_1 = 0.2, v_2 = 0.2, r = 1$.

System $\mathbf{A}_1$		**System $\mathbf{A}_2$**	
FC	RP	FC	RP
$s_1^* = 0.182,\ \ z_1^* = 0$	$s_1^{R*} = 0.018$	$z_1^{**} = -0.041$	$z_1^{R**} = -0.092$
$s_2^* = 0.182,\ \ z_2^* = 0$	$s_2^{R*} = 0.48$	$s^{**} = 0.282,\ z_2^{**} = 0.041$	$s^{R**} = 0.282,\ z_2^{R**} = 0.092$
$a_1^* = 0.182$	$a_1^{R*} = 0.018$	$a_1^{**} = 0.279$	$a_1^{R**} = 0.277$
$a_2^* = 0.182$	$a_2^{R*} = 0.48$	$a_2^{**} = 0.003$	$a_2^{R**} = 0.0065$
$U^* = 0.182$	$U^{R*} = 0.070$	$U^{**} = 0.141$	$U^{R**} = 0.140$

In our example equilibrium effort incentives in both periods under A_1 and full commitment (FC) are moderate (0.182) due to high positive autocorrelation λ. If contracts must be renegotiation-proof (RP) induced second-period effort increases to 0.48 under A_1. From an ex ante perspective second-period incentives of 0.48 are far too high and impose too much risk on the agent. To compensate for this effect the principal reduces first-period effort incentives from 0.182 to 0.018. Nonetheless, total equilibrium surplus for the principal under A_1 decreases from 0.182 under full commitment to 0.070 under renegotiation-proofness. Under late information A_2 induced second-period effort incentives under full commitment are lower than under A_1 due to the (unavoidable) use of signals w_1 and w_2 reflected in second-period market price. Therefore, equilibrium surplus $U^{**} = 0.141$ is significantly lower than under A_1. Similar to A_1 under A_2 sequentially optimal second-period effective incentives are higher (0.0065) than under full commitment (0.003). However, under A_2 incentives are closer to the full commitment optimum (0.182) than under early information (0.48). This is the positive effect of market price compensation via late information in an agency with limited commitment. In the example this effect is strong enough to outweigh the negative effect of contracting on non action-informative measures, $U^{R**} = 0.081 > 0.070 = U^{R*}$.

5 Conclusion

In this paper we contrast early versus late reporting of accounting information in a two period agency setting. Two accounting systems are present and both produce identical information. However, the reporting date of the signals produced differ according to the system in place due to a different degree of conservatism immanent in the set of standards applied. Reporting, however, is a necessary condition for contractibility in our setting. Moreover, we build on the fact that the farther in a distant future a measure is reported, the less useful it becomes for contracting. We reflect this idea in our model by restricting contractibility to measures reported throughout the two period horizon of our game. As a result late reporting prevents the second period accounting signal from being available for contracting at all.

Accounting information is typically not the only source of information that relates to a firm's performance. To reflect this we introduce stock prices as another performance measure available for contracting in addition to reported accounting measures. We carefully model the information content of both types of measures. We assume that the accounting measures produced are informative about the agent's action in each period. The stock price, in contrast, constitutes the expected terminal firm value. It reflects the value relevant accounting measures produced along with other value relevant but non-action-informative information. From a contracting perspective this renders the stock price an unfavorably noisy measure. With respect to timing, we assume that the stock price reflects all information available somewhere in the market. This assumption of strong form efficiency implies that accounting information is reflected in prices once it is produced, no matter whether it has already been reported in financial statements or not. Stock prices therefore remain unaffected by the reporting system in place. The role of accounting in our model is thus one of disciplining the information flow into the market.

Within this structure we derive optimal compensation contracts in a full commitment setting as opposed to a limited commitment setting.

With full commitment we find that an early information system is strictly preferred to a late system. With early information, accounting measures only are used for incentive contracting. Stock prices do not add anything but noise and are at best ignored. If a late reporting system is implemented, however, second period incentives need to be created via contracting on the stock price. Using both, the first and second period stock price allows to hedge some of the additional noise immanent in the stock price measure but still results in an inferior risk and incentive trade-off and in turn increases additional agency costs.

While these results are consistent with previous contributions to the literature and basically what we would expect given our carefully designed setup, it turns out that they do not necessarily hold anymore with limited commitment. Restricting the contract space to renegotiation-proof contracts qualitatively changes the results from above. At least in some settings the late reporting system becomes preferable to the early one and including stock prices in the incentive contract becomes optimal. This may occur if the correlation of accounting signals over time is positive. Such positive correlation creates overly high second period incentives if early reporting is implemented and accounting measures only are used for contracting. Using late reporting and including stock prices into the incentive contracts introduces noise and thus counteracts excessive incentives. This favorable second period effect possibly outweighs a negative first period effect. From a standard setting point of view our results basically show that we have no strong point for either favoring early or late, or alternatively more or less conservative, reporting for several reasons. First, we need to remind ourselves that our results consider only one out of several objectives standard setters are likely to pursue. Second, even if the intention is to provide firms with appropriate performance measures for incentive contracting, this is achieved by requiring early reporting if firms can commit to long term contracts. If they cannot do so, which seems to be the more realistic case, it depends on the particular setting whether early or late reporting is more suitable.

Appendix

Proofs

Proof of Lemma 1

With the participation constraint binding under A_1 the full commitment problem is given by

$$\begin{aligned} \max U &= a_1 + a_2 - \frac{a_1^2}{2} - \frac{a_2^2}{2} - \frac{r}{2} Var\left(s_1 y_1 + s_2 y_2 + z_1 P_1 + z_2 P_2\right) \qquad (5) \\ & \text{subject to} \\ a_1 &= s_1 + \beta z_1 + \beta_{y_1} z_2 \\ a_2 &= s_2 + \beta_{y_2} z_2. \end{aligned}$$

Define $h_1 = s_1 + \beta z_1 + \beta_{y_1} z_2, h_2 = s_2 + \beta_{y_2} z_2, h_3 = \beta z_1 + \beta_{w_1} z_2,$and $h_4 = \beta_{w_2} z_2$. Then by inserting the incentive constraints into U the principal's problem can be represented by

$$U = h_1 + h_2 - \frac{h_1^2}{2} - \frac{h_2^2}{2} - \frac{r}{2}\sigma^2 \left[h_1^2 + h_2^2 + h_3^2 + h_4^2 + 2h_1 h_2 \lambda + 2h_3 h_4 \mu\right].$$

From the first-order conditions for the optimal incentive weights

$$\begin{aligned} \frac{\partial U}{\partial s_1} &= 1 - z_1\beta - z_2\beta_{y_1} - s_1 - \frac{r}{2}\sigma^2 \left[2h_2\lambda + 2h_1\right] = 0 \\ \frac{\partial U}{\partial s_2} &= 1 - z_2\beta_{y_2} - s_2 - \frac{r}{2}\sigma^2 \left[2h_1\lambda + 2h_2\right] = 0 \\ \frac{\partial U}{\partial z_1} &= \beta\left(1 - h_1\right) - \beta r \sigma^2 \left[h_2\lambda + h_4\mu + h_1 + h_3\right] = 0 \\ \frac{\partial U}{\partial z_2} &= \beta_{y_1} + \beta_{y_2} - h_1\beta_{y_1} - h_2\beta_{y_2} - \\ & \frac{r}{2}\sigma^2 \left[2\beta_{y_1} h_2\lambda + 2\beta_{y_2} h_1\lambda + 2\beta_{w_1} h_4\mu + 2\beta_{w_2} h_3\mu + 2h_1\beta_{y_1} + 2\beta_{y_2} h_2 + 2h_3\beta_{w_1} + 2h_4\beta_{w_2}\right] = 0 \end{aligned}$$

we obtain

$$s_1^* = s_2^* = \frac{1}{1 + r\sigma^2 (1 + \lambda)}, z_1^* = 0, z_2^* = 0$$

with the maximum objective function value $U^* = \frac{1}{1+r\sigma^2(1+\lambda)}$.

Proof of Lemma 2

Similar to A_1 the full commitment problem under A_2 is given by

$$\begin{aligned} \max U &= a_1 + a_2 - \frac{a_1^2}{2} - \frac{a_2^2}{2} - \frac{r}{2} Var\left(sy_1 + z_1 P_1 + z_2 P_2\right) \\ & \text{subject to} \\ a_1 &= s + \beta z_1 + \beta_{y_1} z_2 \\ a_2 &= \beta_{y_2} z_2 \end{aligned} \tag{6}$$

Define $u_1 = s + \beta z_1 + \beta_{y_1} z_2, u_2 = \beta_{y_2} z_2, u_3 = \beta z_1 + \beta_{w_1} z_2$, and $u_4 = \beta_{w_2} z_2$. Then by inserting the incentive constraints into U the principal's problem can be represented by

$$U = u_1 + u_2 - \frac{u_1^2}{2} - \frac{u_2^2}{2} - \frac{r}{2}\sigma^2 \left[u_1^2 + u_2^2 + u_3^2 + u_4^2 + 2u_1 u_2 \lambda + 2u_3 u_4 \mu\right].$$

From the first-order conditions for the optimal incentive weights

$$\begin{aligned} \frac{\partial U}{\partial s} &= 1 - z_1\beta - z_2\beta_{y_1} - s - \frac{r}{2}\sigma^2 \left[2u_2\lambda + 2u_1\right] = 0 \\ \frac{\partial U}{\partial z_1} &= \beta\left(1 - u_1\right) - \beta r\sigma^2 \left[u_2\lambda + u_4\mu + u_1 + u_3\right] = 0 \\ \frac{\partial U}{\partial z_2} &= \beta_{y_1} + \beta_{y_2} - u_1\beta_{y_1} - u_2\beta_{y_2} - \\ & \frac{r}{2}\sigma^2 \left[2\beta_{y_1} u_2\lambda + 2\beta_{y_2} u_1\lambda + 2\beta_{w_1} u_4\mu + 2\beta_{w_2} u_3\mu + 2u_1\beta_{y_1} + 2\beta_{y_2} u_2 + 2uh_3\beta_{w_1} + 2u_4\beta_{w_2}\right] = 0 \end{aligned}$$

we obtain

$$\begin{aligned} s^{**} &= \frac{r\sigma^2\beta_{w_2}^2\left(\mu^2 - 1\right) + \beta_{y_2}\left(\beta_{w_2}\mu + \beta_{w_1} + \beta_{y_2} - \beta_{y_1}\right)\left(r\sigma^2\left(\lambda - 1\right) - 1\right)}{N}, \\ z_1^{**} &= \frac{\left(\beta_{w_2}\mu + \beta_{w_1}\right)\beta_{y_2}\left(r\sigma^2\left(\lambda - 1\right) - 1\right)}{N\beta}, z_2^{**} = \frac{\beta_{y_2}\left(r\sigma^2\left(\lambda - 1\right) - 1\right)}{N} \end{aligned}$$

As by definition $\mu\beta_{w_2} - \beta + \beta_{w_1} = 0$ it holds $z_1^{**} = -z_2^{**}$. The equilibrium payoff of the principal is $U^{**} = \frac{r\sigma^2\left[\beta_{w_2}^2\left(\mu^2-1\right)+2\beta_{y_2}^2(\lambda-1)\right]-2\beta_{y_2}^2}{N}$, with $N = r^2\sigma^4\left[\beta_{y_2}^2\left(\lambda^2 - 1\right) + \beta_{w_2}^2\left(\mu^2 - 1\right)\right] + r\sigma^2\left[\beta_{w_2}^2\left(\mu^2 - 1\right) - 2\beta_{y_2}^2\right] - \beta_{y_2}^2$.

Proof of Lemma 3

a) To determine the sequentially optimal incentive weights under A_1 we have to solve the following program:

$$\max_{s_2, z_2} U_2 = a_2 - \frac{a_2^2}{2} - \frac{r}{2} Var\left(s_2 y_2 + z_2 P_2 | y_1, P_1\right)$$

$$\text{subject to } a_2 = \arg\max_{a_2'} \left(E\left(s_2 y_2 + z_2 P_2\right) - \frac{a_2'^2}{2} - \frac{r}{2} Var\left(s_2 y_2 + z_2 P_2 | y_1, P_1\right)\right).$$

Let $X_2 = \left(s_2 + z_2\beta_{y_2}\right) y_2 + z_2 \left(\beta_{w_1} w_1 + \beta_{w_2} w_2\right)$ and $\mathbf{X}_1 = (y_1, P_1)$ then

$$Var\left(s_2 y_2 + z_2 P_2 | y_1, P_1\right) = Var\left(X_2 | \mathbf{X}_1\right) = Var\left(X_2\right) - \Sigma_{21}\Sigma_1^{-1}\Sigma_{21}^T.$$

With

$$\Sigma_{21} = \left(\begin{array}{cc} \sigma^2\lambda\left(s_2 + z_2\beta_{y_2}\right) & \sigma^2\left[\beta\lambda\left(s_2 + z_2\beta_{y_2}\right) + z_2\beta\left(\beta_{w_1} + \beta_{w_2}\mu\right)\right] \end{array} \right)$$

and

$$\Sigma_1 = \left(\begin{array}{cc} \sigma^2 & \beta\sigma^2 \\ \beta\sigma^2 & 2\beta^2\sigma^2 \end{array} \right)$$

we obtain $\Sigma_{21}\Sigma_1^{-1}\Sigma_{21}^T = \sigma^2\left(z_2^2\beta_{w_1}^2 + \lambda^2 s_2^2 + \mu^2 z_2^2\beta_{w_2}^2 + \lambda^2 z_2^2\beta_{y_2}^2 + 2\lambda^2 s_2 z_2\beta_{y_2} + 2\mu z_2^2\beta_{w_1}\beta_{w_2}\right)$.
With $Var\left(X_2\right) = \sigma^2\left(\left(s_2 + \beta_{y_2} z_2\right)^2 + z_2^2\left(\beta_{w_1}^2 + \beta_{w_2}^2 + 2\beta_{w_1}\beta_{w_2}\mu\right)\right)$ we then obtain

$$Var\left(X_2 | \mathbf{X}_1\right) = \sigma^2\left[\left(1 - \lambda^2\right)\left(z_2\beta_{y_2} + s_2\right) + \beta_{w_2}^2 z_2^2\left(1 - \mu^2\right)\right]$$

Incentive compatibility constraint: As the agent's action do not influence the variance of his compensation the incentive constraint can be written as

$$\begin{aligned} a_2 &= \arg\max_{a_2'} E\left(s_2 y_2 + z_2 P_2 | \mathbf{X}_1\right) - a_2'^2/2. \\ &= \arg\max E\left(s_2 y_2 + z_2\beta_{y_2} y_2 | \mathbf{X}_1\right) - a_2'^2/2 \\ &= s_2 + z_2\beta_{y_2}. \end{aligned}$$

Thus, the program to determine s_2 and z_2 can be written as

$$\begin{aligned} &\max U_2 = a_2 - \frac{a_2^2}{2} - \sigma^2\left[\left(1 - \lambda^2\right)\left(z_2\beta_{y_2} + s_2\right) + \beta_{w_2}^2 z_2^2\left(1 - \mu^2\right)\right] \\ &\text{s.t. } a_2 = s_2 + z_2\beta_{y_2}. \end{aligned}$$

Substituting for a_2 in the objective function the principal's program becomes

$$\max_{s_2, z_2} U_2 = s_2 + z_2\beta_{y_2} - \frac{\left(s_2 + z_2\beta_{y_2}\right)^2}{2} - \sigma^2\left[\left(1 - \lambda^2\right)\left(z_2\beta_{y_2} + s_2\right) + \beta_{w_2}^2 z_2^2\left(1 - \mu^2\right)\right].$$

Solving the system of first-order conditions $\left\{\frac{\partial U_2}{\partial s_2} = 0, \frac{\partial U_2}{\partial z_2} = 0\right\}$ for s_2 and z_2 leads to

$$s_2^{R*} = \frac{1}{1 + r\sigma^2\left(1 - \lambda^2\right)}, z_2^{R*} = 0.$$

b) Similar to a) the principal's problem under A_2 is given by

$$\begin{aligned} &\max_{s, z_2} U_2 = a_2 - \frac{a_2^2}{2} - \frac{r}{2} Var\left(s y_1 + z_2 P_2 | y_1, P_1\right) \\ &\text{subject to } a_2 = \arg\max_{a_2'}\left(E\left(s y_1 + z_2 P_2\right) - \frac{a_2^2}{2} - \frac{r}{2} Var\left(s y_1 + z_2 P_2 | y_1, P_1\right)\right). \end{aligned}$$

Let $X_2 = z_2 \left(\beta_{y_2} y_2 + \beta_{w_1} w_1 + \beta_{w_2} w_2\right)$ and $\mathbf{X}_1 = (y_1, P_1)$ then

$$Var\left(sy_1 + z_2 P_2 | y_1, P_1\right) = Var\left(X_2 | \mathbf{X}_1\right) = Var\left(X_2\right) - \Sigma_{21}\Sigma_1^{-1}\Sigma_{21}^T.$$

With

$$\Sigma_{21} = \begin{pmatrix} \sigma^2 \lambda z_2 \beta_{y_2} & z_2 \sigma^2 \left[\beta_{y_2}\beta\lambda + \beta\beta_{w_1} + \beta\beta_{w_2}\mu\right] \end{pmatrix}$$

and

$$\Sigma_1 = \begin{pmatrix} \sigma^2 & \beta\sigma^2 \\ \beta\sigma^2 & 2\beta^2\sigma^2 \end{pmatrix}$$

we obtain $\Sigma_{21}\Sigma_1^{-1}\Sigma_{21}^T = \sigma^2 z_2^2 \left(\lambda^2 \beta_{y_2}^2 + \mu^2 \beta_{w_2}^2 + 2\mu\beta_{w_1}\beta_{w_2} + \beta_{w_1}^2\right)$.

With $Var\left(X_2\right) = \sigma^2 z_2^2 \left(\beta_{y_2}^2 + \beta_{w_1}^2 + \beta_{w_2}^2 + 2\beta_{w_1}\beta_{w_2}\mu\right)$ we then obtain

$$Var\left(X_2 | \mathbf{X}_1\right) = \sigma^2 z_2^2 \left(-\lambda^2 \beta_{y_2}^2 - \mu^2 \beta_{w_2}^2 + \beta_{w_2}^2 + \beta_{y_2}^2\right).$$

Similar to a) the incentive compatibility constraint becomes:

$$\begin{aligned} a_2 &= \arg\max_{a_2'} E\left(sy_1 + z_2 P_2 | \mathbf{X}_1\right) - a_2'^2/2. \\ &= \arg\max E\left(z_2 \beta_{y_2} y_2 | \mathbf{X}_1\right) - a_2'^2/2 \\ &= z_2 \beta_{y_2}. \end{aligned}$$

Thus, the program to determine s and z_2 can be written as

$$\begin{aligned} &\max_{s, z_2} U_2 = a_2 - \frac{a_2^2}{2} - \sigma^2 z_2^2 \left(-\lambda^2 \beta_{y_2}^2 - \mu^2 \beta_{w_2}^2 + \beta_{w_2}^2 + \beta_{y_2}^2\right) \\ &\text{s.t. } a_2 = z_2 \beta_{y_2}. \end{aligned}$$

Substituting for a_2 in the objective function the principal's program becomes

$$\max_{s, z_2} U_2 = z_2 \beta_{y_2} - \frac{\left(z_2 \beta_{y_2}\right)^2}{2} - \sigma^2 z_2^2 \left(-\lambda^2 \beta_{y_2}^2 - \mu^2 \beta_{w_2}^2 + \beta_{w_2}^2 + \beta_{y_2}^2\right)$$

U_2 does not depend on s such that any value of s is renegotiation-proof. Solving the first-order condition $\frac{\partial U_2}{\partial z_2} = 0$ for z_2 leads to

$$z_2^{R**} = \frac{\beta_{y_2}}{\beta_{y_2}^2 \left(1 + r\sigma^2 \left(1 - \lambda^2\right)\right) + \beta_{w_2}^2 r\sigma \left(1 - \mu^2\right)}.$$

Proof of Lemma 4

The optimal A_1- incentive weights under full commitment are given in the proof of Lemma 1.

Calculating the differences of second-period incentive weights under full commitment and renegotiation-proofness (as given by lemma 3) we obtain:

$$s_2^* - s_2^{R*} = \frac{-\lambda(\lambda+1) r\sigma^2}{\left[1+(1+\lambda) r\sigma^2\right]\left[1+\left(1-\lambda^2\right) r\sigma^2\right]}. \tag{7}$$

The denominator of (7) is strictly positive. The numerator is positive (zero, negative) iff λ is negative (zero, positive). Hence, $s_2^* - s_2^{R*} \gtreqless 0$ iff $\lambda \lesseqgtr 0$. As $a_2^{(\cdot)*} = s_2^{(\cdot)*}$ the same relation applies for a_2.

Proof of Lemma 5

Taking the difference of renegotiation-proof second-period (effective) incentive rates $\overline{z}_2^{R**}$ and s_2^{R*} we obtain

$$\overline{z}_2^{R**} - s_2^{R*} = -\frac{r\sigma^2\beta_{22}^2(1-\mu)(\mu+1)}{\left[1+\left(1-\lambda^2\right) r\sigma^2\right]\left[\beta_{21}^2\left(1+r\sigma^2\left(1-\lambda^2\right)\right)+\beta_{22}^2 r\sigma^2\left(1-\mu^2\right)\beta\right]} < 0.$$

Payoffs and first-period incentive rates of renegotiation-proof problems

1) System $\mathbf{A}_1$

a) We have to solve the full commitment problem (5) from the proof of Lemma 1 subject to the renegotiation-proof constraints $s_2 = s_{21}^{R*} = \frac{1}{1+r\sigma^2\left(1-\lambda^2\right)}$ and $z_2 = z_2^{R*} = 0$. The respective unconstrained objective function becomes (with $h_1 = s_1 + \beta z_1, h_2 = s_2, h_3 = \beta z_1$)

$$\max_{s_1,z_1} U = s_1+\beta z_1+s_2^{R*}-\frac{(s_1+\beta z_1)^2}{2}-\frac{\left(s_2^{R*}\right)^2}{2}-\frac{r}{2}\sigma^2\left[(s_1+\beta z_1)^2+\left(s_2^{R*}\right)^2+(\beta z_1)^2+2(s_1+\beta z_1)s_2^{R*}\lambda\right].$$

This optimization problem has the optimal solution

$$s_1^{R*} = \frac{r\sigma^2\left(\lambda^2+\lambda-1\right)-1}{r^2\sigma^4\left(\lambda^2-1\right)+r\sigma^2\left(\lambda^2-2\right)-1}, \; z_1^{R*} = 0$$

and the corresponding objective function value

$$U^{R*} = \frac{r^2\sigma^4\left(2-3\lambda^2+\lambda^4-2\lambda+2\lambda^3\right)+2r\sigma^2\left(2-2\lambda^2-\lambda\right)+2}{2\left(-1-r\sigma^2\left(1-\lambda^2\right)\right)^2\left(1+r\sigma^2\right)}.$$

2) System $\mathbf{A}_2$

We have to solve the full commitment problem (6) from the proof of Lemma 2 subject to the renegotiation-proof constraint $z_2 = z_2^{R**} = \frac{\beta_{y_2}}{\beta_{y_2}^2\left(1+r\sigma^2\left(1-\lambda^2\right)\right)+\beta_{w_2}^2 r\sigma\left(1-\mu^2\right)}$. The respective unconstrained objective function becomes (with $u_1 = s + \beta z_1 + \beta_{y_1} z_2^{R**}, u_2 = \beta_{y_2} z_2^{R**}, u_3 = \beta z_1 + \beta_{w_1} z_2^{R**}$, and $u_4 = \beta_{w_2} z_2^{R**}$)

$$\max_{s,z_1} U = u_1 + u_2 - \frac{u_1^2}{2} - \frac{u_2^2}{2} - \frac{r}{2}\sigma^2\left[u_1^2+u_2^2+u_3^2+u_4^2+2u_1u_2\lambda+2u_3u_4\mu\right].$$

This problem has the following solution

$$
\begin{aligned}
s^{R**} &= \frac{-\left[r\sigma^2\left(\beta_{w_2}\left(1-\mu^2\right)+\beta_{y_2}^2\left(1-\lambda-\lambda^2\right)+\beta_{y_2}\left(\beta-\beta_{y_1}\right)\right)+\beta_{y_2}^2+\beta_{y_2}\left(\beta-\beta_{y_1}\right)\right]}{\left(1+r\sigma^2\right)\left(r\sigma^2\left(\beta_{w_2}^2\left(\mu^2-1\right)+\beta_{y_2}^2\left(\lambda^2-1\right)\right)-\beta_{y_2}^2\right)}, \\
z_1^{R**} &= \frac{\beta_{y_2}}{r\sigma^2\left(\beta_{w_2}^2\left(\mu^2-1\right)+\beta_{y_2}^2\left(\lambda^2-1\right)\right)-\beta_{y_2}^2}.
\end{aligned}
$$

The corresponding objective function value is given by

$$
U^{R**}=\frac{1}{2}\frac{\begin{array}{c} r^2\sigma^4\left[\begin{array}{c}\beta_{w_2}^4\left(\mu^4-2\mu^2+1\right)+\beta_{w_2}^4\left(2-2\lambda-\lambda^2+2\lambda^3+\lambda^4\right)\\ +\beta_{w_2}^2\beta y_2^2\left(2\lambda\left(\mu^2\left(1+\lambda\right)-1-\lambda\right)+3\left(1-\mu^2\right)\right)\end{array}\right] \\ +r\sigma^2\left[\beta_{w_2}^2\beta y_2^2\left(1-\mu^2\right)+2\beta_{y_2}^4\left(2-2\lambda^2-\lambda\right)\right]+2\beta_{y_2}^4\end{array}}{r\sigma^2\left(\beta_{w_2}^2\left(1-\mu^2\right)+\beta_{y_2}^2\left(1-\lambda^2\right)\right)+\beta_{y_2}^2}.
$$

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