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Allocating control in agency problems with limited liability and sequential hidden actions

by

Patrick W. Schmitz

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Bonn Graduate School of Economics
Department of Economics
University of Bonn
Adenauerallee 24 - 42
D-53113 Bonn

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Allocating control in agency problems with limited liability and sequential hidden actions

Patrick W. Schmitz[*]

This paper discusses the optimal organization of sequential agency problems with contractible control actions under limited liability. In each of two stages, a risk-neutral agent can choose an unobservable effort level. A success in the first stage makes effort in the second stage more effective. Should one agent be in control in both stages (integration), or should different agents be in charge of the two actions (separation)? Both modes of organization can be explained on the basis of incentive considerations due to moral hazard, without resorting to commitment problems or ad hoc restrictions on the class of feasible contracts.

[*] University of Bonn and CEPR. Postal address: University of Bonn, Wirtschaftspolitische Abteilung, Adenauerallee 24–42, D-53113 Bonn, Germany. E-mail: <patrick.schmitz@wiwi.uni-bonn.de>. Internet: <http://center.wipol.uni-bonn.de/~schmitz/>.

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1 Introduction

This paper studies a principal-agent model in which the principal decides how to organize a project that consists of two stages. Should the principal employ the same agent to perform both tasks (integration), or is it better to have different agents in charge of the two stages (separation)? The costs and benefits of separating control that are highlighted in this paper are solely based on incentive considerations due to moral hazard concerns. Both modes of organization can thus be explained in a uniform framework without imposing any ad hoc restrictions on the class of feasible contracts.

The two sequential tasks modelled here may e.g. be basic research and more applied R&D activities. In practice, examples for both integration and separation abound. For instance, Nicol (2000) emphasizes that at Bell Laboratories (the heart of R&D at Lucent Technologies), they make a clear distinction between research and development. On the other hand, Wahlster (2002) points out that in the German Research Center for Artificial Intelligence (which works closely with Siemens AG to develop, e.g., the next Internet generation), the same scientists carry out basic research as well as applied R&D and product transfer under one roof. According to Royce (2002), who has managed large software engineering projects for Rational Software Corp., the most discriminating characteristic of a successful software development process is the separation between R&D activities and production activities.[1]

In many cases, a procurer deliberately commits at the outset to hire two separate contractors for distinct stages of a project. For example, the San Diego Association of Governments carried out a congestion pricing project (allowing drivers of single occupant vehicles to pay a toll in order to obtain access to the I-15 Express Lanes in San Diego County, California). When a contractor was searched for Phase One (design of electronic toll collection technology, interim implementation), it was already announced in the Request for Proposals that a separate contractor would be selected for Phase Two (full implementation).[2]

[1] See also Johnson (1996), who argues in favor of a clear separation between research and development in the context of software engineering.

[2] This case is well documented on the Internet, see <http://argo.sandag.org/fastrak/library.html>. Note also that federal-aid highway program statutes generally require States to award separate contracts for highway design and highway construction.

The research question addressed here is closely related to the recent debate on public-private partnerships. In this context, it is typically asked whether construction of a facility such as a prison and service provision should be bundled. In other words, should the government contract with one party to build and subsequently run the prison, or should it contract with one party to build the prison and with another party to run it? This question has been studied by Hart (2003) in an incomplete contracts setting, focused on the hold-up problem. In contrast, the present paper explores the issue from a complete contracting perspective in a pure moral hazard framework.

Specifically, consider the following two-stage game involving a principal and one or two (identical) agents who have no initial resources. All parties are risk-neutral. At each stage, an agent must choose an action ("effort") for which only control is contractible.[3] In other words, while the effort *level* chosen by an agent is unobservable and hence non-contractible, a contract *can* specify ex ante which agent is in control. In each stage, there can either be a success or a failure, which is verifiable. To fix ideas, assume that the principal is the user of an innovation, and an agent is a research unit. The first stage may aim at the development of a new tool, that later on can be used in applied research and development (the second stage).[4] Ultimately, the principal is only interested in the outcome of the second stage, namely whether or not a product is developed that can be commercialized. However, a success in the first stage is assumed to make effort in the second stage more effective (either by decreasing the costs of exerting effort in the second stage or by increasing the productivity of second-stage effort).

Now the basic question is whether control should be allocated to the same agent in both periods (integration), or whether control should be divided, so that one agent is in charge in

[3] In the terminology of Aghion, Dewatripont, and Rey (2001), the actions are "contractible control actions". While they also show that divided control can be optimal in a two-stage model, the logic underlying their work is quite different. In particular, they further depart from the standard moral hazard paradigm by assuming that no output variables are verifiable.

[4] Hence, a two-stage version of Tirole's (1999) "R&D game" in its complete contracting variant is studied here. See Schmitz (2002b) for an adverse selection model of R&D with a related two-stage technology in which the principal performed the first task by herself. See also Rosenkranz and Schmitz (2003), who study a two-stage R&D setting in an incomplete contracting framework.

the first stage and another agent is in charge in the second stage (separation). It is well-known from the literature on task assignment problems that it may be beneficial to let one agent do several tasks, since the rent used to motivate an agent to work hard on one task can have a spillover effect on another task; i.e., integration may simply lead to "rent saving".[5] While this force is also at work in the present setting, a novel effect arises due to the sequential nature of the problem studied here, where the amount of rents necessary to motivate the second-stage effort depends on the outcome of the first stage. The fact that a success in the first stage makes effort in the second stage more effective means that the principal may have to offer the agent in the second stage a higher rent if the first stage was a failure. But this implies that under integration the agent may have an incentive to shirk in the first stage, unless the second stage rent in case of a first stage success is increased over and above the level necessary to motivate an agent to work hard under separation.

In order to see this more clearly, consider the simplest variant of the well-known hidden action model with limited liability.[6] A success yields a verifiable revenue of V to the principal, while a failure yields no revenue. If the agent works hard the success probability is r, while it is only q if he shirks, with $0 < q < r \leq 1$. When the agent works hard, he incurs personal disutility costs c. The principal offers the agent a contract (w_0, w_1) that specifies payments for the cases of failure and success, respectively. Since the agent's decision whether or not to shirk is unobservable, he only works hard if

$$rw_1 + (1-r)w_0 - c \geq qw_1 + (1-q)w_0.$$

Given the fact that the agent has no wealth, the principal sets $w_0 = 0$ and $w_1 = c/(r-q)$ if she wants to induce high effort, and $w_0 = w_1 = 0$ otherwise. The principal induces high effort whenever $V \geq rc/(r-q)^2$. In this case, the agent's rent is $qc/(r-q)$, while it is zero otherwise.

[5] The fact that incentive considerations can lead to economies of scope has been shown in various frameworks, see e.g. Baron and Besanko (1992), Dana (1993), Hirao (1994), Gilbert and Riordan (1995), Laux (2001), Che and Yoo (2001), and Laffont and Martimort (2002, ch. 5).

[6] This model is a building block of many recent contributions to the moral hazard literature, see e.g. Innes (1990), Crémer (1995), Pitchford (1998), Baliga and Sjöström (1998), Demougin and Fluet (1998), Tirole (1999, 2001), Winter (2001), Laux (2001), Che and Yoo (2001), and Laffont and Martimort (2002, ch. 4).

The agent's rent has interesting properties which to the best of my knowledge have so far not been exploited in the literature. Specifically, the rent is increasing in the agent's costs, as long as the principal wants to induce the agent to work hard. Similarly, the rent becomes larger when the effect of effort on the success probability is reduced. This observation has important consequences when one considers sequential tasks with the natural property that success in the first stage makes effort in the second stage more effective (i.e., reduces c or increases r). Assume that the stakes V are sufficiently large so that the principal always wants to implement high effort in both stages. Under integration, the agent might be tempted to shirk in the first stage, in order to increase the rent he expects to receive when he works hard in the second stage.[7] Anticipating this temptation, the principal has to offer higher rents to the agent than she had to offer two agents each in charge of one task, so that separation is strictly optimal. On the other hand, if the stakes V are sufficiently small, it is optimal for the principal to implement high effort in the second stage selectively, i.e. whenever the first stage was successful. In this case the principal strictly prefers integration, offering the agent a positive wage if and only if both stages are successful, which motivates him to work hard in the second stage whenever the first stage was a success. Separation is suboptimal in this case, because the principal had to pay rents to both agents if both stages were a success.

The literature on task assignment and job design has several strands. Some authors such as Dana (1993), Gilbert and Riordan (1995), and Severinov (1999) have taken an adverse selection approach. More closely related to the present framework is the approach taken by authors such as Holmström and Milgrom (1991), Itoh (1992), Hemmer (1995), and Che and Yoo (2001), who focus on moral hazard problems. While the scale economies generated by the "rent saving" effect that can explain integration are a theme developed in that literature, the basic insight of the present paper according to which in a sequential setting separation can be explained without simply assuming technological diseconomies is new. Alternative

[7] This observation may be related to the "ratchet effect" literature (a regulator infers from a high performance an ability to repeat a similar performance in the future and becomes more demanding, so that a regulated firm has an incentive to keep a low profile; cf. Laffont and Tirole, 1993; Meyer, 1995). Yet, this literature assumes either adverse selection or that productivity is initially unknown to everyone (see Fudenberg and Tirole, 1986, and Holmström, 1999, on signal jamming and career concerns), and the driving force is noncommitment.

explanations of separation that can be found in the literature make use of (several combinations of) precontractual private information, acquisition of hidden information, productivity parameters initially unknown to everyone, non-responsiveness to monetary incentives, limited commitment abilities, and exogenous restrictions on the class of feasible contracts. For example, Lewis and Sappington (1997) and Hirao (1994) assume that an agent acquires private information in the first stage, which may make it cheaper to use a different agent in the second stage.[8] No such assumptions are made here, where in a complete contracting environment the benefits of divided control are based on the same kind of incentive considerations that can account for its costs.

The remainder of the paper is organized as follows. In the next section, the basic two-stage model is introduced. In Section 3, the costs and benefits of integration and separation are determined. Situations in which it is possible to condition second-stage control on the first-stage outcome are considered in Section 4. Further modifications and extensions regarding different effort costs and renegotiation are explored in Section 5. Concluding remarks follow in Section 6. All proofs have been relegated to Appendix A, while modified modeling assumptions are considered in Appendix B.

2 The basic model

At some initial date 0, a principal P either proposes a contract to one agent A (integration) or she offers contracts to two agents, A and B (separation). In the basic model, it is assumed that for technological reasons it must be decided at date 0 whether agent A or agent B will be in charge of the second stage.[9] All parties are risk neutral. There is no pre-contractual private information (i.e., there is no adverse selection). The agents are identical, they have no wealth, and their reservation utilities are given by zero. The principal is interested in the production of an innovation, which has a value $V > 0$ to her.

[8] Aghion and Tirole (1997) combine information acquisition with non-responsiveness to monetary transfers, while Riordan and Sappington (1987) combine it with adverse selection. Holmström and Milgrom (1991), Itoh (1992, 1994), and Hemmer (1995) assume linear contracts and rely on risk aversion. Ickes and Samuelson (1987) and Dewatripont, Jewitt, and Tirole (1999) focus on the ratchet effect and career concerns, respectively.

[9] This assumption will be further discussed and relaxed in Section 4.

At date 1, the first stage of production takes place (e.g., the development of a new tool). This stage aims at producing a technology which – if employed – can increase the probability of making the final marketable innovation. Agent A can exert effort $e_1 \in \{0, 1\}$ by incurring effort costs $c_1 e_1$, where $c_1 > 0$. The agent's decision whether or not to shirk is unobservable (hidden action). The verifiable outcome of the first production stage can either be good ($x_1 = 1$) or bad ($x_1 = 0$). It is good with probability pe_1, where $0 < p < 1$.[10]

At date 2, the second stage of production takes place (e.g., search for an innovative product that can be commercialized). This job is either performed by the same agent A (integration) or by the other agent B (separation). The agent in charge can exert effort $e_2 \in \{0, 1\}$ by incurring effort costs $c_2 e_2$, where $c_2 > 0$. Effort is again unobservable. Even if the agent shirks, i.e. if he does not make use of the technology produced at date 1, the innovation is still made with probability q, where $0 < q < 1$. However, if the agent exerts effort, then the probability of making the innovation is given by $r > q$. The value of r depends upon the technology which he can use. If the outcome of the first production stage was good, then the probability of making the innovation is $r = r_1$, while it is only $r = r_0 < r_1 \leq 1$ otherwise. Let x_2 indicate whether the innovation is made ($x_2 = 1$) or not ($x_2 = 0$). Finally, the principal's gross return Vx_2 can be verified and payments can be made.

In this paper no ad hoc restrictions on the class of contracts will be imposed; i.e., a complete contracting (or mechanism design) approach is employed. Let $w^i_{x_1 x_2} \geq 0$ denote the wage that agent $i \in \{A, B\}$ receives given that $x_1 \in \{0, 1\}$ and $x_2 \in \{0, 1\}$ are observed. Without loss of generality, it can be assumed that at date 0 the principal proposes a contract w^j to agent $j \in \{A, B\}$, where $w^j = (w^j_{00}, w^j_{01}, w^j_{10}, w^j_{11})$.[11] Let $e = (e_1, e_2(0), e_2(1))$ denote the effort profile which the principal wants to implement, where $e_2(x_1)$ is the second-stage effort given the outcome x_1 of the first stage.[12]

[10] The assumption that the outcome of the first stage is always bad if no effort is exerted means that the first stage alone would not yield any rents to the agent. This assumption is only made in order to simplify the exposition; a generalization to the case in which there may also be a success if the agent shirks is straightforward.

[11] It is well known that in a pure hidden action framework nothing could be gained if the agents were asked to report their unobservable effort levels. In contrast, incomplete contracting models usually assume that effort levels are unverifiable but observable, which means that they might be revealed using message games.

[12] Although effort is hidden, one can argue that e is part of the contract. As usual, it is assumed that if an

Since the agents are identical, in a first-best world (i.e., if effort were verifiable) it would make no difference whether or not the same agent would be in charge in the two stages. Hence, the costs as well as the benefits of separation that are discussed in what follows are purely based on incentive considerations. In order to simplify the exposition and avoid tedious case distinctions, attention will be restricted to the most interesting case:[13]

Assumption 1.

$$V > \frac{r_1}{(r_1 - q)^2} c_2 > \frac{r_1}{pq(r_1 - r_0)} c_1$$

In particular, the assumption guarantees that the principal will always want to implement high effort in the first stage. It is obvious to see that the principal would be indifferent between separation and integration if (the value of the innovation were so small or the costs were so high that) she preferred to implement low effort in the first stage.

3 Separation versus integration

Separation. Consider first the case in which two different agents are in charge of the two production stages. Obviously, nothing could be gained by conditioning agent A's wage on the outcome of the second stage of production, hence $w_{11}^A = w_{10}^A = w_1^A$ and $w_{01}^A = w_{00}^A = w_0^A$. Agent A is willing to exert high effort ($e_1 = 1$) if the following incentive compatibility constraint is satisfied:

$$pw_1^A + (1 - p)w_0^A - c_1 \geq w_0^A$$

If the outcome of the first stage is good, then agent B is ready to exert high effort ($e_2(1) = 1$) whenever

$$r_1 w_{11}^B + (1 - r_1)w_{10}^B - c_2 \geq qw_{11}^B + (1 - q)w_{10}^B.$$

Analogously, if the outcome of the first stage is bad, then agent B is willing to work hard ($e_2(0) = 1$) whenever

$$r_0 w_{01}^B + (1 - r_0)w_{00}^B - c_2 \geq qw_{01}^B + (1 - q)w_{00}^B.$$

agent is indifferent between shirking and working hard, then he follows what is prescribed by e.

[13] It is straightforward to analyze the cases in which Assumption 1 is not satisfied in analogy to what follows. Yet, there are no additional economic insights to be gained from this analysis.

Note that the agents' participation constraints are automatically satisfied given incentive compatibility and the limited liability constraints $w^A \geq 0$ and $w^B \geq 0$. The principal offers wage schemes in order to maximize her expected profit

$$\begin{aligned}
& e_1 p \left[(e_2(1) r_1 + (1 - e_2(1)) q) \left(V - w_{11}^B \right) \right. \\
& \left. - (1 - (e_2(1) r_1 + (1 - e_2(1)) q)) \, w_{10}^B - w_1^A \right] \\
& + (1 - e_1 p) \left[(e_2(0) r_0 + (1 - e_2(0)) q) \left(V - w_{01}^B \right) \right. \\
& \left. - (1 - (e_2(0) r_0 + (1 - e_2(0)) q)) \, w_{00}^B - w_0^A \right].
\end{aligned}$$

Under the assumptions made, the principal will always implement high effort in the first stage. Yet, it will depend upon the parameter constellation whether she wants to induce high effort in the second stage in any event or only selectively, i.e. whenever the first stage was a success. The following lemma characterizes the optimal contracts which the principal will propose in each of these two situations.

Lemma 1. Consider the case of separation. If the principal wants to implement $e = (1, 0, 1)$, then she will propose the contract $w_0^A = 0$, $w_1^A = c_1/p$ to agent A and $w^B = (0, 0, 0, c_2/(r_1 - q))$ to agent B, so that her expected profit is given by

$$[pr_1 + (1 - p)q] \, V - c_1 - \frac{pr_1}{r_1 - q} c_2.$$

If the principal wants to implement $e = (1, 1, 1)$, she will offer $w_0^A = 0$, $w_1^A = c_1/p$ and $w^B = (0, c_2/(r_0 - q), 0, c_2/(r_1 - q))$, and her expected profit is

$$[pr_1 + (1 - p) r_0] \, V - c_1 - \left[\frac{pr_1}{r_1 - q} + \frac{(1 - p) r_0}{r_0 - q} \right] c_2.$$

Proof. See Appendix A.

The optimal contracts simply correspond to the solution of the standard hidden action model with limited liability. Note that if $e = (1, 1, 1)$, then agent B's expected rent conditional on a failure in the first stage is $qc_2/(r_0 - q)$, while it is only $qc_2/(r_1 - q)$ conditional on a first stage success.

Integration. Assume now that a single agent, say agent A, is in charge of both production stages. Suppose that the outcome of the first stage of production is good. Then the agent is willing to exert high effort in the second stage ($e_2(1) = 1$) if

$$r_1 w_{11}^A + (1 - r_1) w_{10}^A - c_2 \geq q w_{11}^A + (1 - q) w_{10}^A.$$

Now assume a bad outcome of the first stage. The agent then is ready to work hard in the second stage ($e_2(0) = 1$) if

$$r_0 w_{01}^A + (1 - r_0) w_{00}^A - c_2 \geq q w_{01}^A + (1 - q) w_{00}^A.$$

Applying backward induction, the agent is willing to exert high effort in the first stage ($e_1 = 1$) whenever

$$\begin{aligned} & p \Big[e_2(1) \left(r_1 w_{11}^A + (1 - r_1) w_{10}^A - c_2 \right) + (1 - e_2(1)) \left(q w_{11}^A + (1 - q) w_{10}^A \right) \\ & - e_2(0) \left(r_0 w_{01}^A + (1 - r_0) w_{00}^A - c_2 \right) - (1 - e_2(0)) \left(q w_{01}^A + (1 - q) w_{00}^A \right) \Big] \geq c_1. \end{aligned}$$

Given these incentive compatibility constraints and the limited liability constraint $w^A \geq 0$, the principal proposes a contract to the agent in order to maximize her expected profit

$$\begin{aligned} & e_1 p \Big[(e_2(1) r_1 + (1 - e_2(1)) q) \left(V - w_{11}^A \right) \\ & - (1 - (e_2(1) r_1 + (1 - e_2(1)) q)) \, w_{10}^A \Big] \\ & + (1 - e_1 p) \Big[(e_2(0) r_0 + (1 - e_2(0)) q) \left(V - w_{01}^A \right) \\ & - (1 - (e_2(0) r_0 + (1 - e_2(0)) q)) \, w_{00}^A \Big]. \end{aligned}$$

The following lemma describes contracts that are optimal for the principal, depending upon whether she wants to implement high effort in the second stage in any event (i.e., regardless of the outcome of the first stage) or only conditional on a first stage success.

Lemma 2. Consider the case of integration. If the principal wants to implement $e = (1, 0, 1)$, she will propose the contract $w^A = (0, 0, 0, c_2/(r_1 - q))$, so that her expected profit is

$$[p r_1 + (1 - p) q] \, V - \frac{p r_1}{r_1 - q} c_2.$$

If the principal wants to implement $e = (1, 1, 1)$, it is optimal for her to offer

$$w^A = \left(0, \frac{c_2}{r_0 - q}, 0, \frac{c_1}{r_1 p} + \frac{r_0 c_2}{(r_0 - q) r_1} \right)$$

and her expected profit is given by

$$[pr_1 + (1-p)r_0]\, V - c_1 - \frac{r_0}{r_0 - q} c_2.$$

Proof. See Appendix A.

Separation vs. integration. Suppose that the principal wants to implement high effort in the second stage selectively, i.e. whenever the first stage was a success, $e = (1, 0, 1)$. If two different agents are in charge and if both stages are successful, each agent gets a strictly positive wage (see Lemma 1). In contrast, if one agent is in charge in both stages, the principal only needs to pay him the rent necessary to induce effort in the second stage (see Lemma 2). The agent works hard in the first stage just because otherwise he would lose the second-stage rent.[14] As a consequence, integration is optimal. Yet, if the principal wants to always implement high effort, $e = (1, 1, 1)$, this simple 'rent saving' intuition no longer holds true. Recall that under separation the rent of agent B is larger if the first stage was a failure. Hence, if under integration the principal simply offered the same rents for a second stage success as under separation, the agent would not exert effort in the first stage. In order to induce effort in the first stage in case of integration, the principal thus has to increase the wage that the agent receives when both stages are successful, such that the agent's expected rent when he works hard in both stages equals his expected rent if he only works hard in the second stage, $qc_2/(r_0 - q)$. This means that inducing high second-stage effort in any event (i.e., regardless of the first-stage outcome) is more expensive if only one agent is in charge, so that separation is optimal.

It depends upon the project's value whether or not the principal always wants to implement high effort in the second stage. Specifically, the following result can be obtained.

Proposition 1. If the principal's value V for the innovation is sufficiently large,

$$V \geq \frac{1}{r_0 - q} \left(\frac{1}{1-p} c_1 + \frac{r_0}{r_0 - q} c_2 \right),$$

she prefers two different agents to be in control of the two stages (separation). Otherwise, she prefers one agent to be in charge in both stages (integration).

[14] Note that such a wage scheme is reminiscent of the literature on deferred compensation; see Lazear (1981) and Akerlof and Katz (1989).

Proof. See Appendix A.

Recall that the principal would be indifferent between the two modes of organization if the effort levels were not hidden. Thus, the strict preferences for integration or separation derived in the proposition are only based on incentive considerations due to moral hazard concerns.[15]

Collusion. Following the traditional mechanism design approach, so far it has been assumed that the principal can rule out collusion between the agents.[16] This assumption will now be relaxed. Recall that the driving force behind the main result was the fact that under integration an agent might be tempted to deliberately shirk in the first stage in order to get a higher rent in the second stage. Separation was a solution to this problem. However, if the agents can collude, agent B might bribe agent A to shirk in the first stage.

Assume that under separation, after having signed the contract offered by the principal, the agents can collude by writing a side contract with each other. Notice that the effort decisions are still hidden actions, so the side contract can only specify a payment $t_{x_1 x_2}$ that agent B makes to agent A conditional on the outcomes x_1 and x_2. Following Tirole's (1992) "leaky bucket" model, it is assumed that while there is some unspecified mechanism that enforces the side contract, this mechanism is costly to operate and thus only a fraction $\lambda \in (0, 1)$ of the amount that agent B pays is actually received by agent A.

Remark 1. Suppose that the agents can collude. It is still true that the principal prefers separation if the project's value is sufficiently large,

$$V \geq \frac{1}{r_0 - q}\left(\frac{c_1}{1-p} + \left(\frac{(r_1 - r_0)\,pq}{(1-p)\,(r_1 - q)\,(r_0 - q)}\lambda + \frac{r_0}{r_0 - q}\right)c_2\right).$$

Proof. See Appendix A.

In other words, while the cut-off value is now larger than in Proposition 1, qualitatively

[15] If V is strictly larger [smaller] than the cut-off level given in Proposition 1, the principal strictly prefers separation [integration].

[16] There are good reasons to make such an assumption in a complete contracting framework. In principle, if the agents sign a contract which says that they will not collude, the court should enforce this contract and thus refuse to enforce any side payments.

the main result is still valid.[17] In the remainder of the paper, it will again be assumed that the principal can prevent collusion.

4 Conditional control

So far it has been assumed that for technological reasons control over the second stage must be assigned to agent A or to agent B ex ante (i.e., at date 0), and thus independent of the outcome of the first stage. For instance, this assumption is justified if the second task can only be performed by an agent who is trained to do so, and training must occur before the outcome of the first stage, x_1, is realized.[18] It may be prohibitively costly to train both agents, since e.g. training may require access to an asset which for technological reasons cannot be given both agents simultaneously. As a consequence, it is then impossible to condition the assignment of the second task on the realization of x_1.

In contrast, in this section situations are considered where it is possible to determine which agent is in charge in the second stage depending on the outcome of the first stage. Hence, contracts are now given by (w^A, j_0, j_1) and (w^B, j_0, j_1), where $j_{x_1} \in \{A, B\}$ indicates whether agent A or agent B is in charge of the second stage, given $x_1 \in \{0, 1\}$. If the principal wants to implement high effort in the second stage selectively, i.e. whenever the first stage was successful, the results of the basic model continue to hold. However, if the principal wants to implement high effort in any event, she will now set $j_0 = B$, $j_1 = A$, so that agent B is in charge in the second stage if and only if the first stage was a failure.

Lemma 3. Assume that the principal can condition who is in charge in the second stage on the outcome of the first stage. If the principal wants to implement $e = (1, 0, 1)$, it is still optimal to set $j_0 = j_1 = A$. If she wants to implement $e = (1, 1, 1)$, she sets $j_0 = B$, $j_1 = A$,

[17] Note that the case $\lambda = 0$ corresponds to the basic model, while in the case $\lambda = 1$ collusive bribes would entail no efficiency loss, so that the principal would be indifferent between separation and integration if she wanted to implement $e = (1, 1, 1)$.

[18] For example, in the context of a project analyzing the Earth's climate and radiation, NASA argued that replacement of Space Applications Corp. of Vienna, VA, by another contractor would require intensive training of new contract personnel, which would cause unacceptable delays to the mission. See Commerce Business, Daily Issue of August 11, 1998.

and $w^A = (0, 0, 0, c_2/(r_1 - q))$, $w^B = (0, c_2/(r_0 - q), 0, 0)$, so that her expected profit is

$$[pr_1 + (1-p)\, r_0]\, V - \left[p\frac{r_1}{r_1 - q} + (1-p)\,\frac{r_0}{r_0 - q}\right] c_2.$$

Proof. See Appendix A.

Intuitively, if the first stage was a success, the principal makes use of the well-known "rent saving" effect by rewarding A if and only if he is also successful in the second stage. Yet, if the first stage was a failure, the principal now pays A nothing and switches to agent B, so that agent A can no longer have an incentive to shirk in the first stage in order to enjoy a higher rent in the second stage. Since this makes always inducing high effort more attractive, the relevant cut-off level of the project's value below which integration is optimal is now smaller than in the basic model.[19]

Proposition 2. Assume that the principal can condition who is in charge in the second stage on the outcome of the first stage. She will then prefer integration if the value of the project is relatively small, $V < r_0 c_2/(r_0 - q)^2$. Otherwise, she prefers agent B to be in control in the second stage if and only if the first stage was a failure.

Proof. See Appendix A.

5 Modifications and extensions

Different costs. Until now it has been assumed that the costs of exerting effort in the second stage, c_2, are the same for agent A and agent B. However, it might also be the case that agent A's costs are smaller, say because agent A has already gained some experience while working on the first task.[20] Thus, suppose now that agent A's and agent B's second-stage effort costs are given by c_2^A and $c_2^B > c_2^A$, respectively.

Of course, if the costs of agent B are very high, it is always in the principal's interest to let agent A be in charge in both stages. Yet, if the cost advantage of agent A is not too large,

[19] The fact that with sequential actions a switch of control in some states of the world can be optimal has also been observed in the incomplete contracting literature, see e.g. Nöldeke and Schmidt (1998).

[20] The case in which agent B's second stage costs are smaller is less interesting, since this could only make separation even more attractive.

the effect highlighted in this paper can be strong enough so that the principal may sometimes still prefer separation, even though agent B's costs are higher than agent A's costs. However, since $c_2^B > c_2^A$ implies that separation becomes relatively more costly, the relevant cut-off level of the project's value below which the principal prefers integration will now be larger. More precisely, the following result can be obtained.

Proposition 3. Assume that $c_2^A < c_2^B$.

(i) Suppose that second-stage control must be assigned to an agent ex ante. If

$$c_2^B < \left[1 + \frac{pq\,(r_1 - r_0)}{(1-p)q(r_1 - r_0) + r_1(r_0 - q)}\right] c_2^A,$$

Proposition 1 qualitatively remains valid, yet the cut-off value now is

$$\frac{1}{r_0 - q}\left(\frac{c_1}{1-p} + \frac{r_0}{r_0 - q} c_2^B + \frac{pr_1[c_2^B - c_2^A]}{(1-p)(r_1 - q)}\right).$$

Otherwise, the principal chooses integration.

(ii) Suppose that who is in charge in the second stage can be conditional on the outcome of the first stage. If

$$c_2^B < \frac{r_0 - q}{(1-p)r_0} c_1 + \left[1 + \frac{pq\,(r_1 - r_0)}{(1-p)\,r_0\,(r_1 - q)}\right] c_2^A,$$

Proposition 2 remains valid with the cut-off value $r_0 c_2^B/(r_0 - q)^2$. Otherwise, it is optimal for the principal to choose integration.

Proof. See Appendix A.

Renegotiation. So far, the costs and benefits of integration have been explained without imposing ad hoc restrictions on the class of feasible contracts and on the parties' commitment abilities. Yet, whether or not it is reasonable to assume that the principal can commit not to renegotiate is an issue about which economists disagree; see e.g. Tirole (1999) for a recent discussion. Some readers may hence wonder if the results discussed here are qualitatively robust with regard to renegotiation. The purpose of this section is to show that this is indeed the case.[21]

Consider first the basic model in which for technological reasons the principal must decide between separation and integration ex ante. The fact that the principal cannot commit not to renegotiate means that she can no longer credibly threaten to implement a low effort level in the second stage when inducing a high effort level will be in her date-2 interest. Recall that in Section 3 the principal has implemented $e = (1, 0, 1)$ under integration. This is now no longer possible if inducing $e_2(0) = 1$ is sufficiently profitable for the principal at date 2. It has already been shown that $e = (1, 1, 1)$ is cheaper to implement under separation. Hence, the inability to rule out renegotiation can only make integration less attractive, so that the cut-off level of the project's value above which separation is optimal is now smaller than in Proposition 1. Renegotiation thus only strengthens the main result.

Next, consider the variant of the model in which the principal can condition who is in charge in the second stage on the outcome of the first stage. In this case, even if the principal can commit not to renegotiate, she only implements $e = (1, 0, 1)$ when it is also in her date-2 interest to do so. Recall that if at date 2 the principal wants to induce $e_2(0) = 1$, in this variant of the model she can simply do so by switching to agent B, so that agent A's first-stage incentives are not diluted. As a consequence, there is no scope for renegotiation.

Proposition 4. Assume that the principal cannot commit not to renegotiate.

(i) Suppose that second-stage control must be assigned to an agent ex ante. Then Proposition 1 qualitatively remains valid, yet the relevant cut-off value is now given by $r_0c_2/(r_0-q)^2$.

(ii) Suppose that who is in charge in the second stage can be conditional on the outcome of the first stage. Then Proposition 2 remains valid.

Proof. See Appendix A.

[21] For concreteness, it is assumed here that it is the principal who can offer new contracts at date 2. Yet, this assumption is not crucial (in equilibrium, the principal offers renegotiation-proof contracts at date 0, and whether or not a contract is renegotiation-proof does not depend on how a date-2 renegotiation surplus would be split). See also Schmitz (2005).

Project choice. As an interesting application of Proposition 4(i), assume now that at date 0 the principal can choose between two alternative projects. For simplicity, suppose the only difference between the two projects is that project 1 can generate a return $V = V_1$, while project 2 can generate $V = V_2$.

Intuitively, it seems reasonable to conjecture that the principal will choose project 1 whenever $V_1 > V_2$. After all, there is *no* state of the world in which project 2 can yield a higher return than project 1.[22] Nevertheless, the following result holds.

Corollary 1. Assume that the principal cannot commit not to renegotiate and that second-stage control must be assigned to an agent ex ante. Suppose the principal can choose between projects 1 and 2 with $V_1 > V_2$. It is possible that she prefers to pursue project 2 if

$$V_2 < \frac{r_0 c_2}{(r_0 - q)^2} < V_1 < \frac{r_0 c_2}{(r_0 - q)^2} + \frac{c_1}{(1-p)(r_0 - q)}.$$

Proof. See Appendix A.

The reason for this somewhat surprising result is as follows. If the values that the projects can generate are as characterized in the corollary, then under commitment the principal would always choose integration (see Proposition 1). If renegotiation cannot be ruled out, however, the principal will prefer separation in case of project 1, while renegotiation has no impact on project 2 (see Proposition 4(i)). As a consequence, the principal's expected profit can then be smaller if she chooses project 1. In other words, the principal might deliberately pursue inferior projects as a commitment device.

Different costs. Finally, consider again the case of different costs ($c_2^B > c_2^A$) as discussed above, but now assume that renegotiation cannot be ruled out. If for technological reasons the principal must decide between separation and integration ex ante, Proposition 3(i) still holds qualitatively, but the relevant cut-off level of the project's value below which the principal prefers integration now is smaller. The reason is again that if at date 2 it is sufficiently

[22] It is already known that (even under commitment) contractual parties may sometimes prefer a project that yields a lower *expected* return (but a higher return in some states of the world), because a riskier project can provide stronger incentives (cf. Schmitz, 2002a).

profitable for the principal to induce $e_2(0) = 1$ under integration, then renegotiation would take place and thus integration becomes less attractive.[23]

In the variant of the model in which the principal can condition who is in charge in the second stage on the outcome of the first stage, an interesting new problem arises. At first sight, one might guess that if the principal cannot commit not to renegotiate, agent B will never be in charge. After all, even if the principal announces ex ante that she will switch to agent B when the first stage is a failure, she might change her mind once the first stage is completed. At this point in time, it seems to be in the interest of the principal to let agent A be in charge in the second stage, because his costs are smaller. While this intuition turns out to be valid in some circumstances, there are also situations in which renegotiation has no bite. The reason is that due to the wealth constraint agent B must be promised a strictly positive rent. When the principal wants to renege on the original contract and let agent A be in charge although the first stage was a failure, agent B must be compensated. The cost advantage of agent A may be too small to cover this compensation.[24] The following proposition summarizes these results.

Proposition 5. Assume that renegotiation cannot be ruled out and that $c_2^A < c_2^B$.

(i) Suppose that second-stage control must be assigned to an agent ex ante. If

$$c_2^B < \left[1 + \frac{pq\,(r_1 - r_0)}{(1-p)q(r_1 - r_0) + r_1(r_0 - q)}\right] c_2^A,$$

Proposition 1 remains valid with the cut-off value $r_0 c_2^A/(r_0 - q)^2$. Otherwise, it is optimal for the principal to choose integration.

(ii) Suppose that who is in charge in the second stage can be conditional on the outcome of

[23] Moreover, note that separation can now be a valuable commitment device for the principal. Separation may allow her to implement $e_2(0) = 0$ even if this is not possible under integration, because renegotiating to $e_2(0) = 1$ is less profitable under separation when $c_2^B > c_2^A$.

[24] The observation that the presence of wealth constraints (which are *per se* bad for the principal) can have a beneficial effect by mitigating the danger of renegotiation has an interesting parallel to the work of Dewatripont (1988). He argues that the presence of asymmetric information (which *per se* is also bad) can be beneficial by constraining the danger of renegotiation. In both cases, there are rents the presence of which makes ex post renegotiation more difficult to succeed, which is beneficial from an ex ante point of view.

the first stage. If

$$c_2^B < \min\left\{\frac{r_0}{r_0-q}c_2^A, \frac{r_0-q}{(1-p)r_0}c_1 + \left[1+\frac{pq\,(r_1-r_0)}{(1-p)\,r_0\,(r_1-q)}\right]c_2^A\right\},$$

Proposition 2 remains valid with the cut-off value $r_0c_2^A/(r_0-q)^2$. Otherwise, the principal chooses integration.

Proof. See Appendix A.

6 Concluding remarks

Should a principal have two stages of a project be in control of a single agent or should control be divided between two separate agents? This question has been explored in a simple moral hazard model with risk-neutral but cash-limited agents. While the principal may benefit from integration due to the "rent saving" effect if the stakes are relatively small, she prefers separation if the project can generate profits that are sufficiently large, so that high effort should be exerted in the second stage regardless of the outcome of the first stage. Integration is suboptimal in the latter case, because the agent would have an incentive to prejudice second period efficiency in order to capture higher rents.

In the formal analysis it has been assumed that a good outcome of the first stage makes second-stage effort more effective by enhancing the additional success probability associated with higher effort. Alternatively, one might assume that a good outcome of the first stage reduces the second-stage effort costs. In this case, we can expect qualitatively similar results, as should be clear from the discussion in the introduction. Indeed, it is demonstrated in Appendix B that a result in the spirit of Proposition 1 can also be obtained if r is fixed and c_2 is reduced by a first-stage success. All that really matters is the fact that the rent needed to induce high effort in the second stage may be increased by a bad outcome of the first stage. It should be noted that this is not an artifact of the binary effort formulation. In order to see this, observe that the rent would always be zero if effort did not entail any disutility on the agent. Thus, a positive rent when the effort costs are positive means that there must be situations in which increasing the agent's effort costs increases his rent.[25]

[25] Moreover, note that the assumption that only a binary signal is observed could also be relaxed along the

Finally, note that costs and benefits of integration have been explained here by incentive considerations merely based on the established moral hazard paradigm. In contrast to models of the hold-up problem in the incomplete contracting literature pioneered by Grossman and Hart (1986), there was no need to restrict the class of contracts or assume that renegotiation cannot be prevented.[26] To be sure, the logic underlying the argument presented in this paper does not depend upon whether the agents are employees within a firm or managers of different firms. One might argue that this is not a problem because similar organizational issues arise within and between firms. Yet, the incomplete contracting literature has at least partly been motivated by explaining the boundaries of the firm. It is however somewhat questionable whether the existing hold-up models really have more to offer in this regard. Recall that the allocation of ownership in these models is also simply an allocation of control rights. In the present model, the agent in control of a task has the right to decide about the effort level. Property rights arrangements can be explained with hold-up models such as Hart and Moore (1999) *as well as* with models such as the present one *if and only if* the right to be in charge of a certain action is connected to ownership of an asset. This connection so far has not been addressed in the literature that aims at offering a theoretical foundation for the incomplete contracting approach and awaits further research.

lines of Demougin and Fluet (1998), who have shown that in a moral hazard setting with risk-neutral parties all information that is relevant from a mechanism design perspective can be summarized in a binary statistic.

[26] Tirole (1999) has recently pointed out that standard complete contracting tools may have been too hastily dismissed and he has already mentioned the possibility of considering multiple moral hazard models as an alternative to the incomplete contracting approach.

Appendix A

Proofs of Lemmas 1–3, Propositions 1–5, Remark 1, and Corollary 1 follow.

Proof of Lemma 1. The incentive compatibility constraints can be rewritten as follows:

$$e_1 = 1 \text{ whenever } p\left(w_1^A - w_0^A\right) \geq c_1$$

$$e_2(1) = 1 \text{ whenever } (r_1 - q)\left(w_{11}^B - w_{10}^B\right) \geq c_2$$

$$e_2(0) = 1 \text{ whenever } (r_0 - q)\left(w_{01}^B - w_{00}^B\right) \geq c_2$$

Hence, the principal can always set $w_0^A = w_{10}^B = w_{00}^B = 0$. Her expected profit is thus

$$\begin{aligned} &e_1 p\left[(e_2(1)r_1 + (1 - e_2(1))q)\left(V - w_{11}^B\right) - w_1^A\right] \\ &+(1 - e_1 p)\left(e_2(0)r_0 + (1 - e_2(0))q\right)\left(V - w_{01}^B\right). \end{aligned}$$

If the principal wants to implement $e_1 = 1$, she sets $w_1^A = c_1/p$ (and otherwise she sets $w_1^A = 0$). Similarly, if she wants to implement $e_2(\xi) = 1$ for $\xi \in \{0, 1\}$, she sets $w_{\xi 1}^B = c_2/(r_\xi - q)$. The principal's expected profit given $e = (0, 0, 0)$ is qV, given $e = (0, 1, 0)$ it is $r_0\left[V - c_2/(r_0 - q)\right]$. Note that if $e_1 = 0$ then $x_1 = 0$, so that $e = (0, 0, 1)$ and $e = (0, 1, 1)$ are meaningless. Moreover, $e = (1, 0, 0)$ leads to an expected profit of $qV - c_1$ and is thus dominated by $e = (0, 0, 0)$. If $e = (1, 1, 0)$, the expected profit is

$$\left[pq + (1 - p)r_0\right]V - c_1 - \frac{(1 - p)r_0}{r_0 - q}c_2,$$

which is smaller than $\max\left\{r_0\left[V - c_2/(r_0 - q)\right], qV\right\}$, so that $e = (1, 1, 0)$ is inferior to $e = (0, 1, 0)$ or $e = (0, 0, 0)$. Finally, the profits in the remaining cases $e = (1, 0, 1)$ and $e = (1, 1, 1)$ are as given in the Lemma. *Q.E.D.*

Proof of Lemma 2. Note that the incentive compatibility constraints for the second stage are

$$e_2(1) = 1 \text{ whenever } (r_1 - q)\left(w_{11}^A - w_{10}^A\right) \geq c_2,$$

$$e_2(0) = 1 \text{ whenever } (r_0 - q)\left(w_{01}^A - w_{00}^A\right) \geq c_2.$$

Assume that the principal wants to implement $e = (1,1,1)$. The incentive compatibility constraint for the first stage can then be rewritten as follows:

$$\left(r_1 w_{11}^A + (1-r_1) w_{10}^A\right) - \left(r_0 w_{01}^A + (1-r_0) w_{00}^A\right) \geq \frac{c_1}{p}$$

Subject to these constraints, the principal maximizes her expected profit

$$[pr_1 + (1-p)r_0]\, V - p\left[r_1 w_{11}^A + (1-r_1)\, w_{10}^A\right] - (1-p)\left[r_0 w_{01}^A + (1-r_0)\, w_{00}^A\right].$$

Hence,[27] it is optimal for the principal to set $w_{00}^A = 0, w_{01}^A = c_2/(r_0 - q), w_{10}^A = 0$, and

$$w_{11}^A = \max\left\{\frac{c_2}{r_1 - q}, \frac{c_1}{pr_1} + \frac{r_0 c_2}{(r_0 - q)\, r_1}\right\} = \frac{c_1}{pr_1} + \frac{r_0 c_2}{(r_0 - q)\, r_1}.$$

Assume now that the principal wants to implement $e = (1,0,1)$, so that the first stage incentive compatibility constraint reads

$$\left(r_1 w_{11}^A + (1-r_1) w_{10}^A - c_2\right) - \left(q w_{01}^A + (1-q) w_{00}^A\right) \geq \frac{c_1}{p}$$

and her expected profit is

$$[pr_1 + (1-p)\, q]\, V - p\left[r_1 w_{11}^A + (1-r_1)\, w_{10}^A\right] - (1-p)\left[q w_{01}^A + (1-q)\, w_{00}^A\right].$$

She thus sets $w_{00}^A = w_{10}^A = w_{01}^A = 0$ and

$$w_{11} = \max\left\{\frac{c_2}{r_1 - q}, \frac{c_1}{pr_1} + \frac{c_2}{r_1}\right\} = \frac{c_2}{r_1 - q}.$$

Note that one can show analogously that the principal's profit would be equal to

$$[pq + (1-p)\, r_0]\, V - c_1 - \frac{pq + (1-p) r_0}{r_0 - q} c_2$$

if she implemented $e = (1,1,0)$, which is again suboptimal, as is $e = (1,0,0)$. Note also that the principal could achieve the same profits as under separation if she wanted to implement $e_1 = 0$. *Q.E.D.*

Proof of Proposition 1. It has already been shown in the proofs of Lemma 1 and Lemma 2 that the only candidates for effort profiles that the principal might want to implement are

[27] Note that only the expected payments are uniquely determined.

$e = (1,1,1)$, $e = (1,0,1)$, $e = (0,1,0)$, and $e = (0,0,0)$. If the principal wants to implement $e = (1,0,1)$, her expected profit is strictly larger under integration than under separation, since $c_1 > 0$. If she wants to implement $e = (1,1,1)$, she strictly prefers separation, because her expected profit under separation minus her expected profit under integration equals

$$-\left[\frac{pr_1}{r_1 - q} + \frac{(1-p)r_0}{r_0 - q}\right] c_2 + \frac{r_0}{r_0 - q} c_2 = \frac{(r_1 - r_0)\, pq}{(r_0 - q)\,(r_1 - q)} c_2 > 0.$$

Note that even under integration, $e = (1,1,1)$ leads to a larger surplus than $e = (0,1,0)$ whenever $V > c_1/[p(r_1 - r_0)]$, which is always the case given Assumption 1. The principal prefers $e = (1,1,1)$ and separation over $e = (1,0,1)$ and integration whenever

$$\begin{aligned} & [pr_1 + (1-p)r_0]\, V - c_1 - \left[\frac{pr_1}{r_1 - q} + \frac{(1-p)r_0}{r_0 - q}\right] c_2 \\ \geq \;& [pr_1 + (1-p)q]\, V - \frac{pr_1}{r_1 - q} c_2, \end{aligned}$$

which is equivalent to

$$V \geq \frac{1}{(1-p)\,(r_0 - q)} c_1 + \frac{r_0}{(r_0 - q)^2} c_2.$$

Finally, the principal will prefer $e = (1,0,1)$ over $e = (0,0,0)$ whenever $[pr_1 + (1-p)q]\, V - pr_1 c_2/(r_1 - q) \geq qV$, or equivalently $V \geq r_1 c_2/(r_1 - q)^2$, which is always satisfied by Assumption 1. *Q.E.D.*

Proof of Remark 1. Suppose that the principal wants to implement $e = (1,1,1)$ under separation. It is again straightforward to see that it is optimal for the principal to set $w_{01}^A = w_{00}^A = 0$ and $w_{00}^B = w_{10}^B = 0$, and that she can set $w_{11}^A = w_{10}^A = w_1^A$ without loss of generality. Given collusion-proofness, the incentive compatibility conditions imply $w_1^A \geq c_1/p$, $w_{01}^B \geq c_2/(r_0 - q)$ and $w_{11}^B \geq c_2/(r_1 - q)$. It is obviously optimal for the principal to set $w_{01}^B = c_2/(r_0 - q)$, since a higher payment would only make collusion even more attractive. The agents can easily agree on a side contract that induces agent A to shirk by making him pay his wage w_1^A to agent B whenever the first stage is a success. Agent B is willing to pay $t_{01} > 0$ to agent A (implying that agent B will shirk) as long as $q\,[c_2/(r_0 - q) - t_{01}]$ exceeds his no-collusion expected payoff $pr_1 w_{11}^B + (1-p) r_0 c_2/(r_0 - q) - c_2$. Agent A is willing to collude when $\lambda q t_{01}$ exceeds $pw_1^A - c_1$, which he would expect in the absence of collusion. Thus, there is no room for collusion whenever the following constraint is satisfied:

$$\frac{1}{\lambda}\left(pw_1^A - c_1\right) \geq q\frac{c_2}{r_0 - q} - pr_1 w_{11}^B - (1-p)r_0 \frac{c_2}{r_0 - q} + c_2$$

In order to rule out collusion, the principal can either increase w_{11}^B (such that agent B is no longer better off if the first stage fails) or increase w_1^A (such that agent A's rent from working hard is so large that agent B can no longer bribe him to shirk). The cheaper way to avoid collusion is to increase w_1^A, because in order to match a one-unit increase in agent A's rent, agent B must pay $1/\lambda > 1$ units to A. Therefore, $w_{11}^B = c_2/(r_1 - q)$ and

$$w_1^A = \frac{1}{p}c_1 + \lambda \frac{q\,(r_1 - r_0)}{(r_1 - q)(r_0 - q)}c_2,$$

so that the principal's expected profit is

$$[pr_1 + (1-p)r_0]\,V - c_1 - \left[\frac{(1-\lambda)\,pr_1}{r_1 - q} + \frac{(1-p+p\lambda)r_0}{r_0 - q}\right]c_2,$$

which is still larger than the principal's expected profit when she implements $e = (1,1,1)$ under integration. Note that $e = (0,1,0)$ and $e = (0,0,0)$ are still suboptimal. Thus, the principal now prefers $e = (1,1,1)$ and separation over $e = (1,0,1)$ and integration whenever

$$V \geq \frac{1}{r_0 - q}\left(\frac{c_1}{1-p} + \left(\frac{(r_1 - r_0)\,pq}{(1-p)\,(r_1 - q)\,(r_0 - q)}\lambda + \frac{r_0}{r_0 - q}\right)c_2\right)$$

holds.[28] *Q.E.D.*

Proof of Lemma 3. We already know the optimal wage schemes and the resulting expected profits for the cases $j_{x_1} \equiv A$ (integration) and $j_{x_1} \equiv B$ (separation). Suppose first that the principal wants to implement $e = (1,0,1)$. It is easy to see that $(j_0 = A, j_1 = B)$ leads to the same profit as separation, while $(j_0 = B, j_1 = A)$ leads to the same profit as integration, so that the principal cannot gain from conditioning the assignment of who is in charge in the second stage on the outcome of the first stage. Suppose now that the principal wants to implement $e = (1,1,1)$. Consider the case $(j_0 = B, j_1 = A)$, so that agent B is in charge of the second stage if and only if the first stage was a failure. The incentive compatibility conditions for the second stage are as follows:

$$(r_1 - q)\left(w_{11}^A - w_{10}^A\right) \geq c_2$$

[28] Notice that if the principal wants to implement the effort profile $e = (1,0,1)$, she still strictly prefers integration. She cannot simply replicate the integration outcome under separation by letting the agents collude. In order to induce agent A to exert effort, agent B must offer a side payment $t_{11} > 0$ to A. But this means that agent B would no longer have an incentive to work hard in the second stage if the principal only offered him w_{11}^A as derived in Lemma 2.

$$(r_0 - q)\left(w_{01}^B - w_{00}^B\right) \geq c_2$$

The principal will obviously set $w_{01}^A = w_{00}^A = 0$ and $w_{10}^B = w_{11}^B = 0$, so that the incentive compatibility constraint for the first stage reads

$$r_1 w_{11}^A + (1 - r_1) w_{10}^A - c_2 \geq \frac{c_1}{p}$$

and the principal's expected profit is

$$p\left[r_1\left(V - w_{11}^A\right) - (1 - r_1)\, w_{10}^A\right] + (1 - p)\left[r_0\left(V - w_{01}^B\right) - (1 - r_0)\, w_{00}^B\right].$$

It is easy to see that it is optimal for her to set $w_{01}^B = c_2/(r_0 - q)$ and $w_{00}^B = 0$. Moreover,

$$w_{11}^A = \max\left\{\frac{c_2}{r_1 - q}, \frac{c_1}{pr_1} + \frac{c_2}{r_1}\right\} = \frac{c_2}{r_1 - q}$$

and $w_{10}^A = 0$. The principal's expected profit thus is

$$\left[pr_1 + (1 - p)\, r_0\right] V - \left[p\frac{r_1}{r_1 - q} + (1 - p)\, \frac{r_0}{r_0 - q}\right] c_2,$$

which is larger than the expected profit in case of separation. Finally, it is straightforward to check that it cannot be profitable for the principal to set $(j_0 = A, j_1 = B)$. *Q.E.D.*

Proof of Proposition 2. From Lemma 2 and Lemma 3, the principal's expected profit under integration and $e = (1, 0, 1)$ is larger than the principal's expected profit under $e = (1, 1, 1)$ and conditional separation if

$$\begin{aligned} & \left[pr_1 + (1 - p)q\right] V - \frac{pr_1}{r_1 - q} c_2 \\ > \quad & \left[pr_1 + (1 - p)\, r_0\right] V - \left[p\frac{r_1}{r_1 - q} + (1 - p)\, \frac{r_0}{r_0 - q}\right] c_2, \end{aligned}$$

which is equivalent to $V < r_0 c_2/(r_0 - q)^2$. It can be checked in a straightforward way that $e_1 = 0$, $e = (1, 0, 0)$, and $e = (1, 1, 0)$ are still dominated by $e = (1, 1, 1)$ or $e = (1, 0, 1)$. *Q.E.D.*

Proof of Proposition 3.

Part (i). It has already been shown that assigning both stages to agent A is optimal if the principal wants to implement $e = (1, 0, 1)$. Assume that the principal wants to implement

$e = (1,1,1)$. In analogy to Lemma 1 and Lemma 2, it follows that the principal's costs of doing so are

$$c_1 + \left[\frac{pr_1}{r_1 - q} + \frac{(1-p)r_0}{r_0 - q}\right] c_2^B$$

under separation and $c_1 + r_0 c_2^A/(r_0 - q)$ under integration. Hence, if

$$c_2^B < \left[1 + \frac{pq\,(r_1 - r_0)}{(1-p)q(r_1 - r_0) + r_1(r_0 - q)}\right] c_2^A,$$

then the principal still prefers separation if she wants to implement $e = (1,1,1)$. Her expected profits from implementing $e = (1,1,1)$ and $e = (1,0,1)$ are as given in Lemma 1 and Lemma 2 with $c_2 = c_2^B$ and $c_2 = c_2^A$, respectively. The first part of the proposition then follows immediately.

Part (ii). In analogy to Lemma 3 it follows that the principal's costs of implementing $e = (1,1,1)$ with $(j_0 = B, j_1 = A)$ are

$$p\frac{r_1}{r_1 - q}c_2^A + (1-p)\,\frac{r_0}{r_0 - q}c_2^B.$$

Under integration, her costs are again $c_1 + r_0 c_2^A/(r_0 - q)$. Hence, the principal prefers integration if

$$c_2^B \geq \frac{r_0 - q}{(1-p)r_0}c_1 + \left[1 + \frac{pq\,(r_1 - r_0)}{(1-p)\,r_0\,(r_1 - q)}\right] c_2^A.$$

Otherwise, her expected profit from implementing $e = (1,1,1)$ is

$$[pr_1 + (1-p)\,r_0]\,V - p\frac{r_1}{r_1 - q}c_2^A - (1-p)\,\frac{r_0}{r_0 - q}c_2^B,$$

and her expected profit from implementing $e = (1,0,1)$ is

$$[pr_1 + (1-p)q]\,V - \frac{pr_1}{r_1 - q}c_2^A,$$

so that the relevant cut-off value is as stated in the proposition. *Q.E.D.*

Proof of Proposition 4.

Part (i). Note first that the principal only has an incentive to propose a new contract at date 2 if the original contract induced $e_2(0) = 0$, but $V \geq r_0 c_2/(r_0 - q)^2$, so that following $x_1 = 0$ the principal wants to implement high effort in the second stage (cf. the simple one-shot model discussed in the introduction).[29] Hence, $e = (1, 0, 1)$ and integration remain optimal for $V < r_0 c_2/(r_0 - q)^2$. Otherwise, $e_2(0) = e_2(1) = 1$. In this case, $e = (1, 1, 1)$ and separation are optimal due to the same arguments as in the proof of Proposition 1.

Part (ii). From Proposition 2 it is known that $e = (1, 0, 1)$ is only implemented if $V < r_0 c_2/(r_0 - q)^2$, in which case the principal has no interest to induce $e_2(0) = 1$. Otherwise, already in Proposition 2 the principal induces $e_2(0) = e_2(1) = 1$, so that there is no scope for renegotiation. *Q.E.D.*

Proof of Corollary 1. Let $V_1 = r_0 c_2/(r_0 - q)^2 + \varepsilon$ and $V_2 = r_0 c_2/(r_0 - q)^2 - \varepsilon$, where $\varepsilon > 0$ is small, such that the condition stated in the Corollary is satisfied. The principal's expected profit from project 2 (with $e = (1, 0, 1)$ and integration) is then given by

$$[pr_1 + (1-p)q]\, V_2 - \frac{pr_1}{r_1 - q} c_2,$$

while the expected profit from project 1 (with $e = (1, 1, 1)$ and separation) is given by

$$[pr_1 + (1-p)r_0]\, V_1 - c_1 - \left[\frac{pr_1}{r_1 - q} + \frac{(1-p)r_0}{r_0 - q}\right] c_2.$$

If $\varepsilon \to 0$, then a straightforward calculation shows that the expected profit of project 2 converges to a number that is c_1 units larger than the number to which the expected profit of project 1 converges. Hence, there are values V_1 and V_2 such that the principal prefers project 2 even though $V_1 > V_2$. *Q.E.D.*

Proof of Proposition 5.

Part (i). Assume that

$$c_2^B < \left[1 + \frac{pq\,(r_1 - r_0)}{(1-p)q(r_1 - r_0) + r_1(r_0 - q)}\right] c_2^A,$$

because otherwise it is known from Proposition 3 that the principal will never prefer separation. In analogy to the proof of Proposition 4, it follows that integration remains optimal if $V < r_0 c_2^A/(r_0 - q)^2$. If $V \geq r_0 c_2^A/(r_0 - q)^2$, it remains to show that the principal will

[29] Note that if at date 0 the principal wants to implement $e_2(0) = 0$, it still cannot be in her interest to offer in the original contract a positive wage following $x_1 = 0$, because this would only strengthen her temptation to renegotiate at date 2.

not choose integration and $e_1 = 0$, $e_2(0) = 1$. In this case her expected profit would be $r_0 \left[V - c_2^A/(r_0 - q)\right]$, which is smaller than

$$[pr_1 + (1-p)r_0]\, V - c_1 - \left[\frac{pr_1}{r_1 - q} + \frac{(1-p)r_0}{r_0 - q}\right] c_2^B,$$

her expected profit under $e = (1,1,1)$ and separation, because

$$V > \frac{c_1}{p(r_1 - r_0)} - \frac{1}{p(r_1 - r_0)} \left(\frac{r_0 c_2^A}{r_0 - q} - \left[\frac{pr_1}{r_1 - q} + \frac{(1-p)r_0}{r_0 - q}\right] c_2^B \right)$$

under the assumptions made. Hence, the principal will clearly choose separation if $V \geq r_0 c_2^A/(r_0 - q)^2$. Whether she will then implement $e = (1,0,1)$ or $e = (1,1,1)$ depends upon whether V is smaller or larger than $r_0 c_2^B/(r_0 - q)^2$.

Part (ii). Assume that

$$c_2^B < \frac{r_0 - q}{(1-p)r_0} c_1 + \left[1 + \frac{pq\,(r_1 - r_0)}{(1-p)\,r_0\,(r_1 - q)}\right] c_2^A,$$

because otherwise the principal will always prefer integration (see the proof of Proposition 3). If $V < r_0 c_2^A/(r_0 - q)^2$, integration again remains optimal. Otherwise, it is easy to show that integration and $e_1 = 0$, $e_2(0) = 1$ must be dominated by $e = (1,1,1)$ and conditional separation ($j_0 = B, j_1 = A$) under the assumptions made. Note that now it is no longer possible to implement $e = (1,0,1)$ and separation, because the principal would let agent A choose $e_2(0) = 1$ at date 2. Thus, it remains to check whether $e = (1,1,1)$ and conditional separation is implementable or if the principal will have an incentive to renegotiate to $j_0 = A$. It is again straightforward to see that the principal will offer agent B a contract $w^B = \left(0, w_{01}^B, 0, 0\right)$. If $x_1 = 0$ and the principal wants to renegotiate, she must pay agent B his expected rent $r_0 w_{01}^B - c_2^B$ and in order to induce agent A to work hard she will offer him $w_{01}^A = c_2^A/(r_0 - q)$. On the other hand, if she sticks to the original contractual arrangement, her expected payment to agent B is $r_0 w_{01}^B$. Hence, the principal will not renegotiate if $r_0 w_{01}^B - c_2^B + r_0 c_2^A/(r_0 - q) \geq r_0 w_{01}^B$. Note that she cannot rule out renegotiation by increasing w_{01}^B since she must pay $r_0 w_{01}^B$ to agent B anyway. Thus, the principal will not renegotiate if $c_2^B \leq r_0 c_2^A/(r_0 - q)$. Otherwise, she will renegotiate so that she can only implement $e = (1,1,1)$ at the costs derived in the analysis of integration. *Q.E.D.*

Appendix B

First-stage outcome affects second-stage effort costs. Assume now that while a first-stage success has no impact on the second-stage success probability, it decreases the second-stage effort costs. Thus, r does not depend on x_1, but now $c_2 = c_2^H$ if $x_1 = 0$ and $c_2 = c_2^L$ if $x_1 = 1$, where $c_2^H > c_2^L$. In order to avoid tedious case distinctions, assume that $V > rc_2^L/(r-q)^2$ and $c_1 < p \min\left\{qc_2^L, r(c_2^H - c_2^L)\right\}/(r-q)$, which ensures that the principal will always implement high effort in the first stage. In analogy to Section 3 one can show the following results.

First, consider separation. If the principal wants to implement $e = (1, 0, 1)$, she will offer the contract $w_0^A = 0$, $w_1^A = c_1/p$ to agent A and $w^B = \left(0, 0, 0, c_2^L/(r-q)\right)$ to agent B, so that her expected profit is given by

$$[pr + (1-p)q]\, V - c_1 - \frac{pr}{r-q} c_2^L.$$

If the principal wants to implement $e = (1, 1, 1)$, she will propose $w_0^A = 0$, $w_1^A = c_1/p$ and $w^B = \left(0, c_2^H/(r-q), 0, c_2^L/(r-q)\right)$, and her expected profit is

$$rV - c_1 - \frac{r}{r-q}\left[pc_2^L + (1-p)c_2^H\right].$$

Next, consider integration. If the principal wants to implement $e = (1, 0, 1)$, she will offer the contract $w^A = \left(0, 0, 0, c_2^L/(r-q)\right)$, so that her expected profit is

$$[pr + (1-p)q]\, V - \frac{pr}{r-q} c_2^L.$$

If the principal wants to implement $e = (1, 1, 1)$, it is optimal for her to propose

$$w^A = \left(0, \frac{c_2^H}{r-q}, 0, \frac{c_1}{rp} + \frac{qc_2^H + (r-q)c_2^L}{(r-q)r}\right)$$

and her expected profit is

$$rV - c_1 - pc_2^L - \frac{pq + (1-p)r}{r-q} c_2^H.$$

In analogy to Proposition 1, the following result can now be obtained. If the principal's value V is sufficiently large,

$$V \geq \frac{1}{r-q}\left(\frac{1}{1-p} c_1 + \frac{r}{r-q} c_2^H\right),$$

she chooses separation and implements $e = (1, 1, 1)$. Otherwise, she chooses integration and implements $e = (1, 0, 1)$. Hence, the basic insight is robust with regard to the modified modeling assumptions.

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