DISCUSSION
PAPER SERIES
IN ECONOMICS
AND MANAGEMENT

Commitment and Contract Design Under Common Uncertainty and Additional Information Signals

Herbert Dawid &

Michael Kopel

Discussion Paper No. 00-05

GERMAN ECONOMIC ASSOCIATION OF BUSINESS
ADMINISTRATION - GEABA

Commitment and Contract Design Under Common Uncertainty and Additional Information Signals*

Herbert Dawid† and Michael Kopel‡

Abstract

We consider a repeated interaction between a manufacturing firm and a subcontractor. The relationship between the two parties is characterized 1) by moral hazard, 2) by the fact that they do not have perfect knowledge about the base cost level of the project carried out by a subcontractor (the parties only have identical a priori beliefs) and 3) that both subcontractor and manufacturer have access to an additional signal about the base cost level. We consider a two-period model where the players can update their estimate of the base cost level according to incoming information. Short term and long term relationships which are governed by short or long term contracts are compared in terms of the overall expected price of the projects. It is shown that in such a dynamic framework with common uncertainty the precision of the additional signal plays a crucial role in determining the characteristics of the optimal relationship: long term relationships with long term contracts are preferable if the precision of additional information about the base cost level is high. If the precision of the additional signal is low, short term contracts with frequent changes of the subcontractors are optimal for the manufacturer.

JEL Classification: C72, D82, D83
Keywords: Agency Relationships, Moral Hazard, Commitment, Learning

*The authors would like to thank W.B. MacLeod for helpful comments on an earlier version of this paper. This research was supported by the Austrian Science Foundation under Grant F 01005.

†Department of Economics, University of Southern California, Los Angeles

‡Department of Managerial Economics and Industrial Organization, University of Technology, Vienna

1 Introduction

In this paper we use a dynamic principal agent model to address the question under which circumstances a manufacturer should enter contracts with long term commitment with its suppliers and under which circumstances arm's length supplier relationships are preferable. Empirical research shows that the design of supplier contracts vary significantly between regions and industries. A particularly well-illustrated example is the difference in the management of the supply chain of firms in the US and Japanese automobile industries (see Dyer et al. [1998]). Supplier relations in the US are governed by short term contracts where competition is almost solely price-based, whereas Japanese subcontracting is dominated by long term relationships where suppliers are given design and production responsibilities. Unfortunately, there are only few theoretical studies which try to shed light on the reasons for such differences. Here we mention Taylor and Wiggins [1997], who argue that differing cost structures are the main reason for the differing contract design. In contrast to their work, we will show that different degrees of information exchange between members of an information network might also imply such different forms of supply chain management. The motivation for our approach stems from the empirical observation that Japanese automakers have networks of keiretsu suppliers with whom they have close relationships and a high degree of information sharing (e.g. Lincoln et al. [1998]). We will illustrate that access to precise additional information about the properties of the projects carried out by the subcontractor can give long term contracts a competitive edge with respect to short term contracts.

In the agency literature the relationship between short and long term contracts has been the object of numerous studies. The case of a standard moral hazard problem is well understood by now, and in such a framework the principal would always prefer to write long term contracts if she can do so. However, the question under which circumstances a long term contract can be implemented by a succession of short term contracts is much harder to answer. Fudenberg et al. [1990] identify conditions which guarantee that for any sequentially optimal long term contract the payment in period t depends only on the outcome at time t and that action and payment plans are identical to those in the optimal contract that would be observed in the corresponding one-period problem. They show that, in the absence of consumption smoothing and wealth effects there are no relevant intertemporal effects in these finitely repeated moral hazard models and the optimal long term contract can be implemented by a repetition of identical short term contracts. A crucial assumption in this standard setup is that both players in the game have perfect knowledge about the 'technology'. This technology is employed by the agent to generate a certain output where this output depends stochastically on the agent's effort. Usually, if the assumption that both players have perfect knowledge is relaxed, it is still taken for granted that at least the agent possesses perfect information with regard to the technology. So an adverse selection problem arises where the information about certain structural parameters of the technology are private knowledge of the agent (see e.g. Laffont and Tirole [1990]).

In our work we use a two-period extension of a static moral hazard model which has been introduced by Kawasaki and McMillan [1987] to study the importance of incentives and risk aversion in Japanese subcontracting firms. A simple two-period version of the static model would meet all the conditions given in Fudenberg et al. [1990] and, consequently, in repeated supplier-manufacturer relationships short and long term contracts would be equally efficient. However, in this study we consider two additional aspects of such relationships which allow us to better understand the differences in the manufacturer-subcontractor relations described above. First, instead of following the literature and assuming that the cost structure of the subcontractors (the technology) is common knowledge, we rather assume that both partners are a priori uncertain about some parameters of the agent's output function. In the framework of automobile industry supplier relationships such uncertainty may e.g. arise if due to a new car design the requirements for the parts supplied by the subcontractor change[1]. Note that in a static context the standard moral hazard model is well suited to deal with such type of uncertainty, because the output function is usually assumed to be stochastic and the uncertainty could just be regarded as part of the stochastic influence on the output. However, if we assume that the two partners interact for several periods, both players can infer information about the unknown parameters of the model from the outcome in previous periods, i.e. they can learn over time. The second point we will address is the question in how far additional information about this unknown parameter might

[1] Further examples for such common uncertainty come to mind in different interpretations of such a principal agent model. If a firm starts to sell a new product in a previously unserved market, both the management and the sales representatives will be uncertain about the potential sales volume which is possible for sales people (Lal and Srinivasan [1993]). One might also think of a software firm which is awarded a contract for an innovative software project. Then, typically, at the beginning both partners are not able to anticipate which problems might occur and how much money and time have to be invested for the software development.

influence the characteristics of the type of relationship a producer prefers.

In contrast to literature cited above, which takes the length of the relationship as given and focuses on the optimal contract under these circumstances, we strictly distinguish two aspects here: first, the length of the relationship – should the producer hire the same or different subcontractors in the two periods – and, in case the same subcontractor is hired for both projects, should one long term or two short term contracts be used. We model the additional information by the presence of an unbiased signal about the unknown parameter which is observed by both parties between the two periods. The precision of the signal plays a considerable role, since it can be taken for granted that manufacturers within a supplier network have better access to information than firms which rely on competitive markets. This framework then enables us to study the interplay between the information structure and the optimal length and contract design in supplier relationships.

It will turn out that given the learning behavior of the players the interplay between the parties' common uncertainty and the precision of the additional information may have a substantial impact on the design of an optimal contract. In particular, we will show that long term relationships are preferable for the principal if the precision of the additional information is high. On the other hand, short term relationships with frequent changes of subcontractors are preferable if the precision of the signal is low. Hence, our results are able to explain the empirical evidence, if we accept that firms which do not operate in a network (U.S. automobile industry) do not have access to precise additional signals about the cost structure of their suppliers, whereas firms which are embedded in a keiretsu group or a similar information network typically open up information channels through which additional information about the subcontractors base costs can be accessed.

The paper is organized as follows. In section 2 we present the static model and in section 3 we extend the model to a two period framework with learning. Section 4 deals with short term relationships. Section 5 considers three contract types in long run relationships – short term contracts, long term contracts and renegotiation-proof long term contracts – and compares them with short term relationships. We conclude with a discussion of the results in section 6.

2 The Static Model

Following Kawasaki and McMillan [1987], we consider a situation where a manufacturing firm interacts with a subcontractor. The firm offers the subcontractor a compensation scheme indicating the payment the subcontractor will receive for carrying out a project on behalf of the firm. The actual costs of the project can be observed after it has been finished, but the firm cannot observe in how far the subcontractor has expended effort in order to minimize the costs of the project. Thus, we have a typical moral hazard model, where the firm is the principal and the subcontractor is the agent (in what follows we will always refer to the principal by using the female pronoun and to the agent by using the male pronoun). If the subcontractor agrees to carry out the project, the costs are given by

$$c = c^* + \omega - \xi, \tag{1}$$

where c^* are the base costs of the project, ξ is the effect of cost reducing actions of the subcontractor and ω is a normally distributed noise term with zero mean and variance σ^2. The subcontractor has personal costs from the effort expended to reduce project costs of

$$h(\xi) = \frac{\xi^2}{2\delta}, \quad \delta > 0. \tag{2}$$

Effort is not directly observable by the firm. However, the firm can observe the overall costs of the project, c, and thus can condition the payment to the subcontractor on this value. In particular, the offered contract specifies the price to be paid as[2]

$$p = b + \alpha(c - b), \tag{3}$$

where b is the anticipated cost level of the project and the cost sharing parameter $\alpha \in [0, 1]$ determines which fraction of the deviation of actual from anticipated costs is covered by the principal. The principal is assumed to be risk neutral, whereas the agent has CARA utility function of the

[2] Kawasaki and McMillan [1987] use linear contracts. However, this class of contracts is only optimal under rather restrictive assumptions, in particular it has to be assumed that the actual process of outcomes is a Brownian motion where the agent can influence the drift rate by continuous actions during the period, but the principal is only able to observe the aggregate costs at the end of the project (see Holmstrom and Milgrom [1987]). Hellwig and Schmidt [1998] derive similar results for the case where the Brownian motion is approximated by a discrete process.

form $U(u) = \frac{1-e^{-\lambda u}}{\lambda}$, where $\lambda > 0$ is the degree of absolute risk aversion. The problem of the principal is to determine the optimal values of b and α such that the total expected price to be paid is minimized under the agents individual rationality and incentive compatibility constraints.

It can be easily derived (see Kawasaki and McMillan [1987] for details) that, given an incentive rate $(1-\alpha)$ which determines the fraction of cost overrun the subcontractor has to cover himself, the agent optimally chooses

$$\xi^* = \delta(1-\alpha). \tag{4}$$

This in turn implies that the principal should set the incentive rate as

$$(1-\alpha^*) = \frac{\delta}{\lambda\sigma^2 + \delta}. \tag{5}$$

The resulting expected price – which coincides with the expected costs for the principal – is given by

$$\mathbb{E}p = u_0 + c^* - \frac{\delta^2}{2(\lambda\sigma^2 + \delta)}. \tag{6}$$

3 Two Period Framework With Learning

We will extend the static framework with respect to three crucial aspects. First, we consider a dynamic setup where the firm has projects of identical complexity to be carried out by subcontractors for several periods. For reasons of simplicity we restrict our attention to two periods. Depending on whether long or short term contracts are considered, the contract signed in period one determines the payment for both periods or a second contract has to be signed in period two. The utility of a subcontractor is given by $U(u)$, where $u = u_1 + u_2$ is the subcontractor's total net payoff for both periods. The net payoff in any period where he does not enter a contract with the principal is assumed to be u_0. Second, we relax the assumption that principal and agent have perfect information about the base cost level c^*. We rather assume that both have identical a priori beliefs about this value. In particular, we assume that at the beginning of period 1 the parties believe that c^* is normally distributed[3] with expected value $\bar{c}_1$ and variance $\sigma^2_{1,c}$. After the first period they update their beliefs using the observations made. Principal and agent observe the actual costs of the project carried out in

[3] In the dynamic framework the indices always denote the period. We assume that the two noise terms ω_1 and ω_2 are stochastically independent.

period one and update their beliefs about c^*. Third and finally, we assume that an additional signal about the base cost c^* is made public between the two periods. This noisy signal which we denote by $\hat{c}$ might, for example, come from an observation of the actual costs of a similar project carried out by some other subcontractor and, in particular, incorporates the fact that additional information is available to manufacturers and suppliers who participate in an information network. The signal is unbiased and may be written as

$$\hat{c} = c^* + \epsilon,$$

where $\epsilon \sim \mathcal{N}(0, \sigma_s^2)$ is assumed to be stochastically independent from $\omega_i,\ i = 1, 2$. If the parameter σ_s^2 equals zero, the firm can exactly infer c^* from its analysis after the first period. It is important to point out that the signal is observed after the end of the first period. This means that a first period short term contract cannot be written conditional on this additional signal. It is assumed that the signal is observed before the parties update their beliefs and write the second period contract. However, the conclusions would not change if the additional signal would be observed during the second period. The costs which arise in order to obtain the additional signal $\hat{c}$ after the first period are considered as fixed costs and we do not analyze the question under which circumstances bearing these costs is profitable. Here we focus on the interplay of the precision of the signal and the optimal length of the relationship.

Both players use c_1 and $\hat{c}$ in order to update their beliefs about c^* at the beginning of period two. Using Bayesian updating (see De Groot [1970]) this yields

$$\bar{c}_2(\hat{c}, \bar{c}_1, c_1 + \xi_1) = \frac{\sigma_s^2 \sigma^2 \bar{c}_1 + \sigma_s^2 \sigma_{1,c}^2 (c_1 + \xi_1) + \sigma^2 \sigma_{1,c}^2 \hat{c}}{\sigma_s^2 \sigma^2 + \sigma_s^2 \sigma_{1,c}^2 + \sigma^2 \sigma_{1,c}^2} \tag{7}$$

and variance

$$\sigma_{2,c}^2 = \frac{\sigma_s^2 \sigma_{1,c}^2 \sigma^2}{\sigma_s^2 \sigma^2 + \sigma_s^2 \sigma_{1,c}^2 + \sigma^2 \sigma_{1,c}^2}. \tag{8}$$

Note that $c_1 + \xi_1$ is an unbiased estimator of c^* based on information received at the end of period one. Although the principal cannot observe ξ_1, she expects an action from the agent and in equilibrium this expectation is always correct. Thus, we do not distinguish between the actual and the expected action in our notation here.

It is important to realize that in a situation where c^* is common knowledge the results by Fudenberg et al. [1990] would imply that the optimal long term contract is simply the repetition of identical optimal short term contracts and, accordingly, is also renegotiation proof. Hence, it neither makes a difference whether the manufacturer enters a short term (one period) or a long term relationship (two periods) with its subcontractor nor – in case she enters a long term relationship – what kind of contract is used. However, if c^* is not common knowledge the crucial assumption that current and future technological opportunities are common knowledge is not satisfied. Thus, we should not expect that these results still hold in such a framework.

In what follows we will compare short term and long term relationships in terms of the price the principal expects to pay in such a dynamic framework with common uncertainty and learning. Furthermore, we will discuss the implications of different contract forms in the case of long term relationships and illustrate the influence of the precision of the additional signal on the expected price. In recent work the impact of learning in moral hazard models has been investigated, see Bergeman and Hege [1998], Dawid [1998], Mantrala et al. [1997] or Srinidhi and Sen [1997]. In particular, some of the effects of the presence of common uncertainty in moral hazard models have been studied. For example, Gibbons and Murphy [1992]) illustrate the implications of uncertainty about the manager's ability and career concerns on the optimal contract design. They consider a relationship where both parties can a priori not exactly judge the ability of the manager and investigate the interplay between explicit and implicit incentives. Beliefs about the manager's ability are updated in each period and the manager tries to influence the market's perception of his ability by investing high effort in the beginning of his career. In this framework it is optimal to increase explicit incentive rates over time. Meyer [1995] and Meyer and Vickers [1997] also investigate explicit and implicit incentive effects in a dynamic framework with common uncertainty. They focus on the impact of comparative performance information on efficiency properties in a dynamic setup. Our setup is formally close to these models. However, in contrast to these studies we deal with a case where the common uncertainty does not concern the ability of the agents but the characteristic of the project carried out by the subcontractor[4]. Also, we focus on the impact of the length of the relationship and the resulting differences of writing short and long term contracts. Finally, the previous studies of the effect of common uncertainty did not consider the possibility that additional information is received between the two periods.

[4]We are aware of a single exception where uncertainty about job characteristics is considered, namely a model of job swapping in Meyer and Vickers (1997). However, in their model an additional signal between the periods is not present.

4 Short Term Relationships

First, we will analyze the optimal design of contracts in a short term relationship where no player commits to an interaction in the second period when signing the first period deal. Since the subcontractor is not awarded with another contract in the second period, he does not take any possible effects of his first period action on the second period contract into account. The time line for this case is given in figure 1.

Insert Figure 1 here

If short term contracts of the form

$$p_i = b_i^S + \alpha_i^S(c_i - b_i^S) \quad i = 1, 2$$

are signed for both periods, the problem of finding the optimal contract reduces to the task of twice designing the optimal contract for the static game. Accordingly, we can use the solution of the static model if c^* is known (nevertheless, since we will refer to some of the intermediate results later on, we give a brief derivation of the outcomes here). All we have to do is take into account the uncertainty about this parameter. The implication of the uncertainty about c^* is that, given the information set of the players, the costs c_i in period i appear as random variables with distribution

$$c_i \sim \mathcal{N}(\bar{c}_i - \xi_i, \sigma_{i,c}^2 + \sigma^2).$$

Note that the players know that c^* is deterministic – although they do not know its value – and accordingly they consider their estimator of c^* and ω_i to be stochastically independent. A contract (α_i^S, b_i^S) gives the agent a net payoff of

$$u_i = b_i^S + \alpha_i^S(c_i - b_i^S) - c_i - \frac{\xi_i^2}{2\delta}$$

and the certainty equivalent of this payoff is

$$CE_i = (1 - \alpha_i^S)(b_i^S - \bar{c}_i + \xi_i) - \frac{\xi_i^2}{2\delta} - \frac{\lambda}{2}(1 - \alpha_i^S)^2(\sigma_{i,c}^2 + \sigma^2)$$

It is easy to see that this expression is maximized for

$$\xi_i^*(\alpha_i^S) = \delta(1 - \alpha_i^S) \quad i = 1, 2 \tag{9}$$

so we get exactly the same reaction functions as in the static case (see (4)).

In order to calculate the optimal incentive rate, we use the fact that the agents participation constraint in period i

$$(1-\alpha_i^S)(b_i^S-\bar{c}_i)+\frac{(1-\alpha_i^S)^2}{2}(\delta-\lambda(\sigma_{i,c}^2+\sigma^2))\geq u_0,$$

is binding in equilibrium in order to express b_i^S in terms of α_i^S:

$$b_i^S=\frac{u_0}{1-\alpha_i^S}+\bar{c}_i+\frac{1-\alpha_i^S}{2}(\lambda(\sigma_{i,c}^2+\sigma^2)-\delta). \tag{10}$$

The principal wants to minimize the price she expects to pay in period i. Using (10) this amount can be expressed as

$$\begin{aligned}&\mathbb{E}_i p_i\\ &= (1-\alpha_i^S)b_i^S+\alpha_i^S\mathbb{E}_i c_i\\ &= u_0+\bar{c}_i+\frac{(1-\alpha_i^S)^2}{2}(\lambda(\sigma_{i,c}^2+\sigma^2)+\delta)-\delta(1-\alpha_i^S),\end{aligned}$$

where $\mathbb{E}_i$ denotes the expectation conditional on the information of the players at the beginning of period i. Minimizing this expression yields the optimal incentive rate. We summarize the results in our first proposition:

Proposition 1 *The incentive rate in the optimal short term contract for period $i=1,2$ has the form*

$$1-\alpha_i^{S*} = \frac{\delta}{\lambda(\sigma_{i,c}^2+\sigma^2)+\delta} \tag{11}$$

$$\tag{12}$$

and the principal expects to pay the price

$$\mathbb{E}_i p_i=u_0+\bar{c}_i-\frac{\delta^2}{2(\lambda(\sigma_{i,c}^2+\sigma^2)+\delta)}, \tag{13}$$

where $\bar{c}_2$ and $\sigma_{2,c}^2$ are given by (7) and (8).

Note that the incentive rate does not depend on the expected value of c^*, but only on the variance of the estimator of the base costs. This is due to the fact that wealth effects do not matter since the agent's utility function exhibits constant absolute risk aversion (see also Gibbons and Murphy [1992]). Since the variance of the estimator decreases from period to period, we can conclude that the incentive rates in short term contracts increase over time.

If we want to calculate the agency costs arising in the framework of short term relationships we first have to determine the optimal solution if no moral hazard is present and the principal can directly observe the action of the agent, but still is uncertain about the base cost level c^*. It is easy to see that in such a case the principal would induce the action $\xi_i = \delta$ in every period by paying the agent $P_i = u_0 + c_i + \frac{\delta}{2}$ whenever he takes this action and zero in all other cases. Here, the subjectively expected price the manufacturer would have to pay is

$$\mathbb{E}_i P_i = u_0 + \bar{c}_i - \frac{\delta}{2}$$

and the expected agency costs are

$$AC_i = \mathbb{E}_i p_i - \mathbb{E}_i P_i = \frac{\delta\lambda(\sigma_{i,c}^2 + \sigma^2)}{2(\lambda(\sigma_{i,c}^2 + \sigma^2) + \delta)}.$$

Note that the agency costs do not only increase with the variance of the noise term ω_i but also with the uncertainty of the two partners about the base cost level.

5 Long Term Relationships

A general assumption in the last section has been that principal and each agent interact for only one period. It is easy to see that the results derived above do not change if at the beginning of period one the principal plans to offer short term contracts to the same subcontractor for the subsequent two periods as long as the agent does not anticipate it. Basically, this has two reasons: first, the agent's actions still are the same; second, the agent's action in the first period has no influence on the quality of the cost estimation in the second period. In contrast to this, things change considerably if principal and agent commit to a two period relationship at the beginning of period one. Two cases have to be distinguished. First, principal and agent sign a short term contract in period one with the (rational) expectation that another short term contract will be signed in period two. Second, a single contract covering both periods is signed at the beginning of period one. In the next subsection we will discuss the implications of the use of short term contracts in a long term relationship. Then we focus on writing long term contracts with and without the possibility of renegotiations at the beginning of period two.

5.1 Short Term Contracts

Even if short term contracts are used in both periods, the agent's knowledge that he will receive another contract in period two changes the first period short term contract. To understand this, we have to look at the expression for the second period base salary given in (10). Inserting the expression for $\bar{c}_2$ given in (7) shows that the base salary in period two, b_2^{S*}, depends linearly on c_1 with a coefficient

$$\frac{\sigma_s^2 \sigma_{1,c}^2}{\sigma_s^2 \sigma^2 + \sigma_s^2 \sigma_{1,c}^2 + \sigma^2 \sigma_{1,c}^2}.$$

Thus, if the agent anticipates in period one that he will receive the payment $(1-\alpha_2)b_2 + \alpha_2 c_2$ in period two, the effective incentive rate in period one is no longer $1-\alpha_1$ but

$$1-\alpha_1 - \frac{(1-\alpha_2)\sigma_s^2 \sigma_{1,c}^2}{\sigma_s^2 \sigma^2 + \sigma_s^2 \sigma_{1,c}^2 + \sigma^2 \sigma_{1,c}^2}.$$

Accordingly, the agent invests less effort than in the case where he is myopic. Note that this is just an instance of the well-known ratchet effect (see Milgrom and Roberts [1992], Meyer [1995], Meyer and Vickers [1997]). The agent anticipates that high costs in period one increase the a posteriori expectation of the principal about the agent's expectation about c^*, and expends less effort in period one in order to increase his base salary in period two. On the other hand, if the principal takes into account that the relationship will last for two periods and herself anticipates the corresponding reaction of the agent, obviously she will adapt the contract she offers. Straightforward calculations show that the optimal first period incentive rate in a short term contract with two period commitment is given by

$$1-\alpha_1^{SC*} = (1-\alpha_1^{S*})\left(1 + \frac{(1-\alpha_2^{S*})\sigma_s^2 \sigma_{1,c}^2}{\sigma_s^2 \sigma^2 + \sigma_s^2 \sigma_{1,c}^2 + \sigma^2 \sigma_{1,c}^2}\right). \qquad (14)$$

The principal increases the first period incentive rate as a reaction to the lower effort of the agent which is due to the ratchet effect. Observe that the ratchet effect is smaller the higher the precision of the additional signal $\hat{c}$ is. This can be easily understood since the influence of c_1 on the a posteriori estimator $\bar{c}_2$ decreases with decreasing σ_s^2. Obviously, for the second period it is irrelevant whether the two partners have interacted before or not. Hence, $(1-\alpha_2^{SC*}) = (1-\alpha_2^{S*})$ and the expected price in the second period is identical to that in a short term relationship. For the first period we have

$$\mathbb{E}_1 p_1 = u_0 + \bar{c}_1 + \frac{\delta}{2}\left(\frac{\delta}{(\lambda(\sigma_{1,c}^2+\sigma^2)+\delta)}\left(1+\frac{(1-\alpha_2^{S*})\sigma_s^2\sigma_{1,c}^2}{\sigma_s^2\sigma^2+\sigma_s^2\sigma_{1,c}^2+\sigma^2\sigma_{1,c}^2}\right)^2-1\right).$$

Thus, if we compare the first period agency costs for the cases of short and long term relationships, we see that the additional agency costs due to the ratchet effect in the long term relationship are given by

$$\Delta AC_1 = \frac{\delta^2}{2(\lambda(\sigma_{1,c}^2+\sigma^2)+\delta)}\left(\left(1+\frac{(1-\alpha_2^{S*})\sigma_s^2\sigma_{1,c}^2}{\sigma_s^2\sigma^2+\sigma_s^2\sigma_{1,c}^2+\sigma^2\sigma_{1,c}^2}\right)^2-1\right).$$

The additional agency costs increase quadratically with the percentage by which the principal increases the first period incentive rate. Of course, these additional agency costs decrease with decreasing variance of the additional signal. In particular, they vanish if the base cost level can be exactly observed after period one ($\sigma_s^2 = 0$).

These arguments show that as long as short term contracts are used, short term relationships are preferable for the principal as long as the signal $\hat{c}$ has positive variance (see also Meyer and Vickers (1997)). However, as pointed out above, in our model repeated short term contracts might be strictly dominated by the use of a single long term contract for the two period relationship. Such a contract, where the payment scheme for both periods is already fixed at the beginning of the first period, avoids the ratchet effect since the posteriori expectation $\bar{c}_2$ does not influence the payment the agent receives. Thus, no implicit incentives exist in this case. This holds also true if the contract is renegotiation proof. In the next two subsections we will examine if and under which circumstances the use of long term contracts makes a two period commitment preferable for the principal.

5.2 Long Term Contracts

Now we address the question how an optimal contract where both partners commit to a two period interaction should look like. We assume that the contracts are linear in all variables. The focus on this contract form is not completely general even under the assumption that 'piece rate contracts' are used. The principal might also commit in period one to use a piece rate $\alpha_2^L(c_1, \hat{c})$ in period two. However, such a commitment would again introduce implicit incentives for period one and also implement a non-linear contract for the first period. Here we stick to the simple case where incentives for both periods are explicit and additive. As in the standard Holmstrom-Milgrom model the use of such linear contracts is not necessarily optimal. However, if it can be shown that commitment is advantageous even with this contract type the result can only be stronger if contracts are non-linear.

We assume that the firm offers the subcontractor a payment scheme of the form

$$p = 2b^L + \alpha_1^L(c_1 - b^L) + \alpha_2^L(c_2 - b^L) + \beta\hat{c}.$$

If the subcontractor accepts the contract, he has to carry out two projects in the two subsequent periods in order to receive the amount p at the end of period two (see figure 2).

Insert Figure 2 here

The net profit of the agent after the two periods is

$$\begin{aligned} p - c_1 - c_2 - \frac{\xi_1^2}{2\delta} - \frac{\xi_2^2}{2\delta} \\ = \ & (2 - \alpha_1^L - \alpha_2^L)(b^L - c^*) + (1 - \alpha_1^L)(\xi_1 - \omega_1) + (1 - \alpha_2^L)(\xi_2 - \omega_2) \\ & -\frac{\xi_1^2}{2\delta} - \frac{\xi_2^2}{2\delta} + \beta(c^* + \epsilon). \end{aligned}$$

The certainty equivalent of the expected utility of such a contract for the agent, where the expectation is taken at the beginning of period 1, is

$$\begin{aligned} CE \ = \ & (2 - \alpha_1^L - \alpha_2^L)(b^L - \bar{c}_1) + (1 - \alpha_1^L)\xi_1 + (1 - \alpha_2^L)\xi_2 - \frac{\xi_1^2}{2\delta} - \frac{\xi_2^2}{2\delta} + \beta\bar{c}_1 \\ & -(2 - \alpha_1^L - \alpha_2^L + \beta)^2 \frac{\lambda\sigma_{1,c}^2}{2} - \frac{\lambda\sigma^2}{2}((1 - \alpha_1^L)^2 + (1 - \alpha_2^L)^2) - \frac{\lambda\beta^2\sigma_s^2}{2} \end{aligned}$$

Maximizing this expression shows that the reaction functions of the agent are – like in the case of short term contracts – given by (9). Analogous to the short term case, knowing that the participation constraint is binding in equilibrium, we can use the equation $CE = 2u_0$ to express b^L in terms of α_1^L and α_2^L in order to derive the following expression for the price the firm expects to pay for both periods:

$$\begin{aligned} \mathbb{E}_1 p \ = \ & 2u_0 + 2\bar{c}_1 - \delta((1 - \alpha_1^L) + (1 - \alpha_2^L)) + \frac{(1 - \alpha_1^L)^2 + (1 - \alpha_2^L)^2}{2} \\ & \cdot(\lambda(\sigma_{1,c}^2 + \sigma^2) + \delta) + (1 - \alpha_1^L)(1 - \alpha_2^L)\lambda\sigma_{1,c}^2 + \frac{\beta^2\lambda}{2}(\sigma_{1c}^2 + \sigma_s^2) \\ & +\beta\lambda\sigma_{1,c}^2((1 - \alpha_1) + (1 - \alpha_2)) \end{aligned} \qquad (15)$$

The principal chooses the incentive rates for both periods and the relative weight on the additional signal $\hat{c}$ such that this expression is minimized. Simple calculations give the following result:

Proposition 2 *The incentive rates and the relative weight on the information variable $\hat{c}$ in the optimal long term contract is given by*

$$1-\alpha_1^{L*} = 1-\alpha_2^{L*} = \frac{\delta(\sigma_s^2+\sigma_{1,c}^2)}{\sigma_s^2(\delta+\lambda(2\sigma_{1,c}^2+\sigma^2))+\sigma_{1,c}^2(\delta+\lambda\sigma^2)} \quad (16)$$

$$\beta^* = \frac{-2\delta\sigma_{1,c}^2}{\sigma_s^2(\delta+\lambda(2\sigma_{1,c}^2+\sigma^2))+\sigma_{1,c}^2(\delta+\lambda\sigma^2)}. \quad (17)$$

The price the principal expects to pay reads

$$\mathbb{E}_1 p = 2u_0 + 2\bar{c}_1 - \frac{\delta^2(\sigma_s^2+\sigma_{1,c}^2)}{\sigma_s^2(\delta+\lambda(2\sigma_{1,c}^2+\sigma^2))+\sigma_{1,c}^2(\delta+\lambda\sigma^2)}.$$

The expressions derived for the optimal contract in this case can be interpreted in an intuitive way. In fact, the problem of the principal can be decomposed into two problems. On one hand, the principal has to determine the ratio between $1-\alpha_1 = 1-\alpha_2$ and β such that the variance of the beliefs about c^* is reduced as much as possible. On the other hand, she has to determine the optimal incentive rates given the resulting effective uncertainty about c^*. The first problem is a statistical problem, namely to construct an estimator with minimal variance by determining the relative weights in a weighted sum of two estimators. One can easily see that $\frac{\beta}{2(1-\alpha_i)} = \frac{-\mathrm{Cov}(c_i,\hat{c})}{\mathrm{Var}(\hat{c})} = \frac{-\sigma_{1,c}^2}{\sigma_{1,c}^2+\sigma_s^2}$ has to hold (see also Milgrom and Roberts [1992], Banker and Datar [1989]). Using this improved estimator, the effective variance of the beliefs about c^* reduces to

$$\hat{\sigma}_c^2 = \frac{\sigma_s^2\sigma_{1,c}^2}{\sigma_{1,c}^2+\sigma_s^2}. \quad (18)$$

If we would replace $\sigma_{1,c}^2$ by (18) in the expressions of the optimal incentive rates derived for a long term contract without an additional signal, we would get exactly the same result as in the proposition. Note also that if $\sigma_s^2 = 0$ and the signal is used optimally, the agent behaves in the long term contract as if there is no a priori common uncertainty about c^*. Since incentive rates in the optimal short and long term contracts coincide when there is no common uncertainty, the incentive rates are in such a case exactly those given by Kawasaki and MacMillan [1987].

Using this notation we can also easily express the agency costs of the long term contract:

$$AC^L = \frac{\delta\lambda(2\hat{\sigma}_c^2 + \sigma^2)}{\lambda(2\hat{\sigma}_c^2 + \sigma^2) + \delta}.$$

Here it can be seen that increasing σ_s^2 implies increasing $\hat{\sigma}_c^2$ and, hence, an increase in the agency costs.

If we compare the agency costs of this contract type with the agency costs arising in a long term relationship governed by short term contracts it is clear that a long term contract is superior. This is due to the fact that less participation constraints have to be satisfied. The analytical expressions become very involved however, and we only present numerical evidence confirming this intuition.

Insert Figure 3 here

Figure 3 gives a comparison of the expected overall price in a long term relationship if short term respectively long term contracts are used under the assumption that no signal is available between the periods. Certainly, this is an extreme case where the advantage of the long term contract is minimal. Nevertheless, we see that the agency costs of using the long term contract are always smaller and that the difference increases with increasing initial uncertainty about c^*.

Having shown that the use of a long term contract is always beneficial, the question arises whether a long term relationship with such a contract should be preferred to a short term contract with regular switching of agents. In the following proposition, which gives the key result of our study, we show that the answer depends on the precision of the signal.

Proposition 3 *There exists a unique value $\hat{\sigma}_s^2 > 0$ such that the principal prefers to enter a long term relationship using a long term contract when $\sigma_s^2 < \hat{\sigma}_s^2$ and prefers short term contracts with agent switching in every period when $\sigma_s^2 > \hat{\sigma}_s^2$.*

We could also explicitly calculate the switching value $\hat{\sigma}_s^2$, but this gives a rather complicated expression and we abstain from presenting it here.

We can also provide an intuitive argument for this result. On one hand, the use of a long term contract increases the agency costs because it establishes a linkage between the two periods. Although there are no implicit incentives and, therefore, no ratchet effect, we still have an effect which we refer to as the correlation effect. Since there is common uncertainty about the base cost level, the two cost values c_1 and c_2 are positively correlated given the information at the beginning of period one[5]. Thus, the conditional variance of the agent's net profit of the long term contract is larger than two times the conditional variance of c_1. This leads to larger risk premiums in both periods and, hence, the optimal incentive rate is decreased in the long term contract to compensate for this effect. Consequently, the agency costs increase. On the other hand, due to the presence of the additional signal, a second effect of the use of a long term contract has to be taken into account as well. If a long term contract is used, the signal $\hat{c}$ can be used to reduce the effective variance of the agents first period net payoff. This reduces the risk premium in the first period and thus increases the incentive rate in a long term contract in comparison to a short term contract where this signal cannot be used. Obviously, this effect is not present in the second period, since the signal can be used also in the short term contract. The bottom line of the argument is that the expected price depends on whether the correlation or the information effect dominates and that this depends on the precision of the signal.

It should be clear that the optimal long term contract we have discussed here is, in general, not renegotiation proof. Thus, such contracts are only credible if both partners can commit to abstain from renegotiations after the first period. In many cases such commitment will be difficult to achieve. In the following subsection we will examine in how far the findings above change if renegotiations cannot be ruled out.

5.3 Renegotiation Proof Long Term Contracts

Up to now we have ignored the possibility that the contract may be renegotiated after the first period. Allowing for renegotiations means that we consider scenarios where the conditions of the contract can be changed at the beginning of period 2 if both partners agree to do so. Note that although the value of $\bar{c}_2$ influences the expected payoff from the old contract at the time of the renegotiation, a change in this value leads simply to a transfer between the two players, which means that it can never lead to a Pareto improvement. Therefore, the agent still has no incentive to increase $\bar{c}_2$ and, accordingly, there are again no implicit incentives here. If renegotiations cannot be ruled out, the well-known renegotiation principle says that

[5] Such an effect has been also observed in adverse selection problems, see Riordan and Sappington [1987].

we can restrict our attention to renegotiation proof contracts when looking for the optimal long term contract. In order to find the optimal renegotiation proof long term contract we first characterize all renegotiation proof contracts.

Proposition 4 *A linear long term contract is renegotiation proof if and only if*

$$1-\alpha_2^L = 1-\alpha_2^{S*} \tag{19}$$

It is easy to understand that in a renegotiation proof long term contract the incentive rate in the second period has to be the same as in a short term contract in period two. Thus, it is larger than the corresponding incentive rate in an optimal long term contract where renegotiations are a priori ruled out. Using proposition 4 it is straightforward to determine the incentive rates and the relative weight on the additional signal for an optimal renegotiation proof long term contract.

Proposition 5 *In an optimal renegotiation proof long term contract the incentive rates in the two periods and the relative weight on the additional signal $\hat{c}$ are given by*

$$\begin{aligned}
1-\alpha_1^{LR*} &= \max\left(0, \frac{\delta((\lambda\sigma^2+\delta)(\hat{\sigma}_c^2+\sigma^2)-\lambda\hat{\sigma}_c^4)}{(\lambda(\hat{\sigma}_c^2+\sigma^2)+\delta)(\lambda(2\hat{\sigma}_c^2\sigma^2+\sigma^4)+\delta(\hat{\sigma}_c^2+\sigma^2))}\right)\\
1-\alpha_2^{LR*} &= \frac{\delta(\hat{\sigma}_c^2+\sigma^2)}{\lambda(2\hat{\sigma}_c^2\sigma^2+\sigma^4)+\delta(\hat{\sigma}_c^2+\sigma^2)}\\
\beta^* &= -\frac{((1-\alpha_1^{LR*})+(1-\alpha_2^{LR*}))\sigma_{1,c}^2}{\sigma_{1,c}^2+\sigma_s^2},
\end{aligned}$$

where $\hat{\sigma}_c^2$ is given by (18). The incentive rate in the first period is lower and in the second period higher than in an optimal linear long term contract.

We do not give the full analytic expression for the expected overall price of the manufacturer in an optimal renegotiation proof long term contract. However, since renegotiation proof contracts are a subset of all linear contracts, it is clear that it is larger or equal than for the optimal long term contract discussed in the previous subsection.

Let us now compare the overall price of a renegotiation proof long term contract with that generated by two short term contracts (with a two period commitment). Gibbons and Murphy (1992) show for a model without an external signal between the periods that the incentive rates and agency costs of repeated short term contracts coincide with the agency costs of the renegotiation proof long term contract. As pointed out above, if an additional signal can be used in the long term contract, the uncertainty about the base cost level c^* can be reduced and lead to an effective variance of $\hat{\sigma}_c^2 < \sigma_{1,c}^2$. Since in the first period short term contract the uncertainty about c^* is characterized by $\sigma_{1,c}^2$, it is clear that the sum of the agency costs over two periods for a renegotiation proof long term contract is smaller than those generated by repeated short term contracts governing a long term relationship. Hence, even if renegotiations cannot be ruled out, the use of a long term contract is preferable in a long term relationship.

The additional participation constraint arising if short term contracts are used lead to a reduction of efficiency.

The principal would like to postpone the payment for the first period project until the signal $\hat{c}$ has been observed in order to reduce the uncertainty about c^* and, accordingly, enable her to reduce the risk premium which is included in the price. However, the first period participation constraint precludes this. In contrast, the use of long term contracts allows such a postponement and therefore decreases the risk premium.

Comparing the agency costs of long term and short term relationships under a scenario with potential renegotiations we get qualitatively very similar results than without renegotiations:

Proposition 6 *If renegotiations cannot be ruled out, the principal still prefers a long term relationship with a long term contract for sufficiently small σ_s^2. Short term relationships are preferable for sufficiently large σ_s^2.*

Unfortunately, the complexity of the analytical expressions for the agency costs precludes a proof which shows that – like in the case without renegotiations – a unique switching value exists, where long term relationships are preferable for a precise signal and short term relationships for low precision. However, all numerical evidence suggests that such a unique value exists.

We close this section by depicting the optimal incentive rates and corresponding expected prices for the various contract types in dependence of the variance of the additional signal $\hat{c}$ in figure 4.

Insert Figures 4a - 4c.

It can be clearly seen that long term relationships are most efficient for a small σ_s^2 whereas short term relationships with frequent changes of subcontractors are preferable if the precision of the signal is low. Observe that the threshold value of the variance of $\hat{c}$ is larger if renegotiations can be ruled out. In the case of a long term relationship, short term contracts are always less attractive than long term contracts.

6 Summary and Discussion

For the sake of clarity, in Table 1 we summarize our results. Our main findings establish a link between the optimal duration of the relationship between a manufacturer and a supplier and the precision of an additional signal. If the quality of the additional signal about the base cost level of the project is high, then a long term relationship results in a lower expected price for the manufacturer. If, however, the precision of the signal is low, then short term contracts with frequent supplier switching is preferable for the manufacturer.

Insert Table 1 here

These theoretical results derived from our extended principal-agent framework match well with the empirical evidence. As mentioned before, typically U.S. firms rely on competitive bidding with frequent supplier switching and low information exchange between the parties. If we accept that a very noisy additional signal captures a situation where the subcontractor is the only source of information and no (or better, only imprecise) additional information about the base costs can be accessed via other information channels, then our analysis shows that the arm's length strategy employed in the U.S. automobile industry is indeed optimal. On the other hand, the close ties of Japanese manufacturing firms and its suppliers via a keiretsu group or other information network typically open up information channels by interlocking directorship, regular meetings of the company, and exchange of executives and managers as well as engineers (Tabeta [1998]). These lines of communication give additional information about the subcontractors base costs. Since this results in a higher precision of the additional signal about the base cost level, long term relationships are indeed the preferable form. Hence, an alternative way to explain the typically observed contracting practices of U.S. and Japanese automobile manufacturers focuses on the information structure which governs these different environments.

Our model opens some channels for further research. We just mention three possibilities. First, from our analysis of the cases with a very imprecise signal, it follows that in such a situation it is crucial that the subcontractor cannot be sure that he will be able to get another short term contract in a subsequent period. In fact, it is optimal for the principal to make the subcontractor believe that he will not be awarded with another contract. In cases where changing subcontractors yields switching costs, it might, however, not be optimal to actually change the subcontractor every period. This gives rise to another interesting problem, namely how to choose the probability for changing the subcontractor after a period. The trade-off to be considered here is that frequent changes lead to high expected switching costs but support the subcontractors beliefs that they are in a short term relationship and thus lead to a weakening of the ratchet effect.

Second, throughout this paper we have implicitly assumed that in the case of short term contracts with commitment the agent does not have the option to follow a 'take the money and run' strategy by choosing the socially optimal effort in the first period and quitting in the second. If such behavior is feasible, it is easy to see that whenever the principal expects the agent to stay and writes the optimal contract according to these beliefs, the agent will follow the take the money and run strategy. On the other hand, he will stay and choose a lower first period effort whenever the principal offers a contract based on the belief that the agent will quit after period one. Thus, in such a case the use of a long term contract which prevents the agent from quitting seems to be attractive, especially if due to switching costs the strategy to fire a subcontractor after every period is rather costly for the principal.

Finally, an interesting extension of this model deals with the case where the precision of the additional signal depends on the agent's first period action. Such a situation occurs if the additional cost information stems from an internal complexity analysis of the project by the subcontractor. We will address the problems mentioned above in more detail in future work.

Appendix

Proof of Proposition 3:
Assume that $\sigma_s^2 = 0$ and let us first consider the case of short term relationships. Here it is easy to see that we have $\bar{c}_2(\hat{c}, c_1 + \xi_1) = \hat{c} = c^*$ and $\sigma_{2,c}^2 = 0$. Inserting these values into (13) and keeping in mind that $\mathbb{E}_1 c^* = \bar{c}_1$ gives after collecting terms

$$\mathbb{E}_1(p_1 + p_2) = 2u_0 + 2\bar{c}_1 - \delta^2 \frac{2(\lambda\sigma^2 + \delta) + \lambda\sigma_{1,c}^2}{2(\lambda(\sigma_{1,c}^2 + \sigma^2) + \delta)(\lambda\sigma^2 + \delta)}.$$

Considering the long term contract we get for $\sigma_s^2 = 0$

$$1 - \alpha_1^{L*} = 1 - \alpha_2^{L*} = \frac{\delta}{\delta + \lambda\sigma^2}$$

and

$$\beta^* = \frac{2\delta}{\delta + \lambda\sigma^2}.$$

The overall price the firm expects to pay at the beginning of period one reads

$$\mathbb{E}_1 p = 2u_0 + 2\bar{c}_1 - \frac{\delta^2}{\delta + \lambda\sigma^2}.$$

The difference between the two overall expected prices is

$$\Delta p = E_1(p_1 + p_2) - \mathbb{E}_1 p = \frac{\delta^2 \lambda\sigma_{1,c}^2}{2(\delta + \lambda\sigma^2)(\lambda(\sigma_{1,c}^2 + \sigma^2) + \delta)} > 0$$

and we have shown that the principal strictly prefers the long term contract for $\sigma_s^2 = 0$. On the other hand, for $\sigma_s^2 \to \infty$ we have

$$\mathbb{E}_1 p \to 2u_0 + 2\bar{c}_1 - \frac{\delta^2}{\delta + \lambda(2\sigma_{1,c}^2 + \sigma^2)},$$

and accordingly

$$\begin{aligned} \Delta p &= \frac{\delta^2}{\delta + \lambda(2\sigma_{1,c}^2 + \sigma^2)} - \frac{\delta^2}{2(\delta + \lambda(\sigma_{1,c}^2 + \sigma^2))} - \frac{\delta^2}{2(\delta + \lambda(\sigma_{2,c}^2 + \sigma^2))} \\ &< \frac{\delta^2}{\delta + \lambda(2\sigma_{1,c}^2 + \sigma^2)} - \frac{\delta^2}{\delta + \lambda(\sigma_{1,c}^2 + \sigma^2)} < 0. \end{aligned}$$

Thus the difference Δp between the two overall expected prices written as a function of σ_s^2 is positive at zero and negative at plus infinity.

Short introspection shows that the price difference written with a common denominator is quadratic in σ_s^2 which implies that it has a unique positive root $\hat{\sigma}_s^2$. □

Proof of Proposition 4

Consider an arbitrary long term contract $p = 2b^L + \alpha_1^L(c_1 - b^L) + \alpha_2^L(c_2 - b^L) + \beta\hat{c}$.

Assume further that the principal deliberates to offer the agent a new contract of the form $\tilde{p} = \tilde{b}^L + \tilde{\alpha}_2^L(c_2 - \tilde{b}^L)$ after c_1 and $\hat{c}$ have been observed. Since the agent has to agree to switch to the new contract, his expected utility from the new contract must be at least as high as his expected utility from the old one. The certainty equivalent of his expected utility from the old contract given $c_1, \hat{c}$ and ξ_1 reads (after his reaction function in period two has been inserted)

$$CE = (2-\alpha_1^L-\alpha_2^L)b^L-(1-\alpha_1^L)c_1+\beta\hat{c}-(1-\alpha_2^L)(\bar{c}_2-\delta(1-\alpha_2^L))-\frac{\xi_1^2}{2\delta}-\frac{(1-\alpha_2^L)^2}{2}(\lambda(\sigma_{2,c}^2+\sigma^2)+\delta).$$

Calculating the certainty equivalent of the new contract and equalizing the two values yields

$$\begin{aligned}(1-\tilde{\alpha}_2^L)\tilde{b}^L &= (2-\alpha_1^L-\alpha_2^L)b^L+\alpha_1^Lc_1+\beta\hat{c}+((1-\tilde{\alpha}_2^L)-(1-\alpha_2^L))\bar{c}_2\\ &\quad+\frac{(1-\tilde{\alpha}_2^L)^2-(1-\alpha_2^L)^2}{2}(\lambda(\sigma_{2,c}^2+\sigma^2)-\delta).\end{aligned}$$

Straightforward calculations show now that the conditional expected price stemming from the contract $\tilde{p}$ is minimized for

$$1-\tilde{\alpha}_2^L = \frac{\delta}{\lambda(\sigma_{2,c}^2+\sigma^2)+\delta} = 1-\alpha_2^{S*},$$

Thus, if the principal offers a new contract after period one , she offers one with incentive rate $(1-\alpha_2^{S*})$. The difference in the expected overall costs of the two contracts conditional on the information available after period one is

$$\mathbb{E}_2(\tilde{p}-p) = [\frac{(1-\alpha_2^{S*})^2}{2}(\lambda(\sigma_{2,c}^2+\sigma^2)+\delta)-\delta(1-\alpha_2^{S*})]-[\frac{(1-\alpha_2^L)^2}{2}(\lambda(\sigma_{2,c}^2+\sigma^2)+\delta)-\delta(1-\alpha_2^L)].$$

The original contract is renegotiation proof if and only if this difference is non-negative and it is obvious that the difference is non-negative if and only if $\alpha_2^L = \alpha_2^{S*}$. □

Proof of Proposition 5:
The value of β^* follows from the arguments given in the previous subsection and, given this value, the effective uncertainty about c^* at the beginning of period one is reduced to $\hat{\sigma}_c^2$ given by (18). We know from proposition 4 that $\alpha_2^{LR*} = \alpha_2^S*$ and inserting $\sigma_{2,c}^2$ gives the expression in the proposition. To determine the optimal first period incentive rate, the principal has to maximize (15) over $(1-\alpha_1^L)$ given that $\alpha_2^L = \alpha_2^{S*}$. From the first order condition we get

$$1 - \alpha_1^{LR*} = \frac{\delta - \lambda\hat{\sigma}_c^2(1-\alpha_2^{S*})}{\lambda(\hat{\sigma}_c^2 + \sigma^2) + \delta}.$$

Since the incentive rate must be non-negative, the optimal rate is zero whenever this expression is negative. Inserting the full term of $1-\alpha_2^{S*}$ gives the expression stated in the proposition. The fact that $1-\alpha_2^{S*}$ is larger than the second period incentive rate in an optimal long term contract has already been established in the last subsection and together with the first order condition for $1-\alpha_1^{LR}$ this establishes that $1-\alpha_1^{LR*}$ has to be smaller than the corresponding incentive rate in the optimal linear long term contract. □

Proof of Proposition 6:
First, we show that the expected overall price is smaller with a renegotiation proof long term contract than with two short term contracts in short term relationships if $\sigma_s^2 = 0$. It is easy to see that in this case both optimal incentive rates in a renegotiation proof long term contract are given by

$$1 - \alpha_i^{LR*} = \frac{\delta}{\lambda\sigma^2 + \delta}$$

and thus equal those in an optimal short term contract without uncertainty about c^*. On the other hand, if short term contracts are used there is still uncertainty about c^* in the first period (the second period incentive rate of course also equals the one without uncertainty). This immediately yields that the agency costs are larger if short term contracts are used. On the other hand, if the variance σ_s^2 goes to infinity the overall expected price in both cases converges towards the value without an additional signal $\hat{c}$. We know that without such a signal the expected price in a renegotiation proof long term contract is equal to that generated by two short term contracts in a long term relationship. Due to the ratchet effect this is larger than the price generated by two short term contracts in a short term relationship. A simple continuity argument establishes now the proposition. □

References

Banker, R.D., and S.M. Datar, "Sensitivity, Precision, and Linear Aggregation of Signals for Performance Evaluation", *Journal of Accounting Research* (1989), 27, 21-39.

Bergeman, D., and U. Hege, "Venture Capital Financing, Moral Hazard, and Learning", *Journal of Banking & Finance* (1998), 22, 703-735.

Dawid, H., "Repeated Moral Hazard with Boundedly Rational Agents", Working Paper, University of Vienna, 1998.

De Groot, M.H., *Optimal Statistical Decisions* (New York, NY: McGraw-Hill, 1970).

Dyer, J.H., Cho, D.S., and W. Chu, "Strategic Supplier Segmentation: The Next "Best Practice" in Supply Chain Management", *California Management Review* (1998), 40, 57-77.

Fudenberg, D., Holmstrom, B., and P. Milgrom, "Short-Term Contracts and Long-Term Agency Relationship", *Journal of Economic Theory* (1990), 51, 1-31.

Gibbons, R., and K.J. Murphy, "Optimal Incentive Contracts in the Presence of Career Concerns: Theory and Evidence", *Journal of Political Economy* (1992), 100, 468-505.

Hellwig, M., and K.M Schmidt, "Discrete-Time Approximations of the Holmström-Milgrom Brownian-Motion Model of Intertemporal Incentive Provisions", SFB 504 discussion paper No 98-06, University of Mannheim, 1998.

Holmstrom, B., and P. Milgrom, "Aggregation and Linearity in the Provision of Intertemporal Incentives", *Econometrica* (1987), 55, 303-328.

Kawasaki, S., and J. McMillan, "The Design of Contracts: Evidence from Japanese Subcontracting", *Journal of the Japanese and International Economics* (1987), 1, 327-349.

Lal, R., and V. Srinivasan, "Compensation Plans for Single- and Multi-product Salesforces: An Application of the Holmstrom-Milgrom Model", *Management Science* (1993), 39, 777-793.

Laffont, J.-J., and J. Tirole, *A Theory of Incentives in Procurement and Regulation* (Cambridge, MA: MIT Press, 1993).

Lincoln, J.R., Ahmadjian, C.L., and E. Mason, "Organizational Learning and Purchase-Supply Relations in Japan: Hitachi, Matsushita, and Toyota Compared", *California Management Review* (1998), 2, 241-264.

Mantrala, M.K., Raman, K., and R. Desiraju, "Sales Quota Plans: Mechanisms for Adaptive Learning", *Marketing Letters* (1997), 8, 393-405.

Meyer, M.A., "Cooperation and Competition in Organizations: A Dynamic Perspective", *European Economic Review* (1995), 39, 709-722.

—, and J. Vickers, "Performance Comparisons and Dynamic Incentives", *Journal of Political Economy* (1997), 105, 547 - 581.

Milgrom, P., and J. Roberts, *Economics, Organization and Management* (Englewood Cliffs, NJ: Prentice Hall, 1992).

Riordan, M.H., and D.E.M. Sappington, "Information, Incentives and Organizational Mode", *Quarterly Journal of Economics* (1987), 243-263.

Srinidhi, B., and K. Sen, "Analysis of Managerial Contracts under Different Roles of the Human Agent", Working Paper, Rutgers University, 1997.

Tabeta, N., "The Kigyo Keiretsu Organization and Opportunism in the Japanese Automobile Manufacturing Industry", *Asia Pacific Journal of Management* (1998), 15, 1-18.

Table 1

High Precision Signal:
$LL < LR < SS < LS$
Low Precision Signal:
$SS < LL < LR < LS$

Comparison of different contract types in various environments. The first letter describes the length of the relationship (short(S) - long(L)), the second the type of contract used (short(S) - long without renegotiations(L)-renegotiation-proof(R)). The sign '<' indicates that the overall price the firm expects to pay is smaller.

Figure Captions:

Figure 1: Time line for the interaction via short term contracts.

Figure 2: Time line for the interaction via a long term contract.

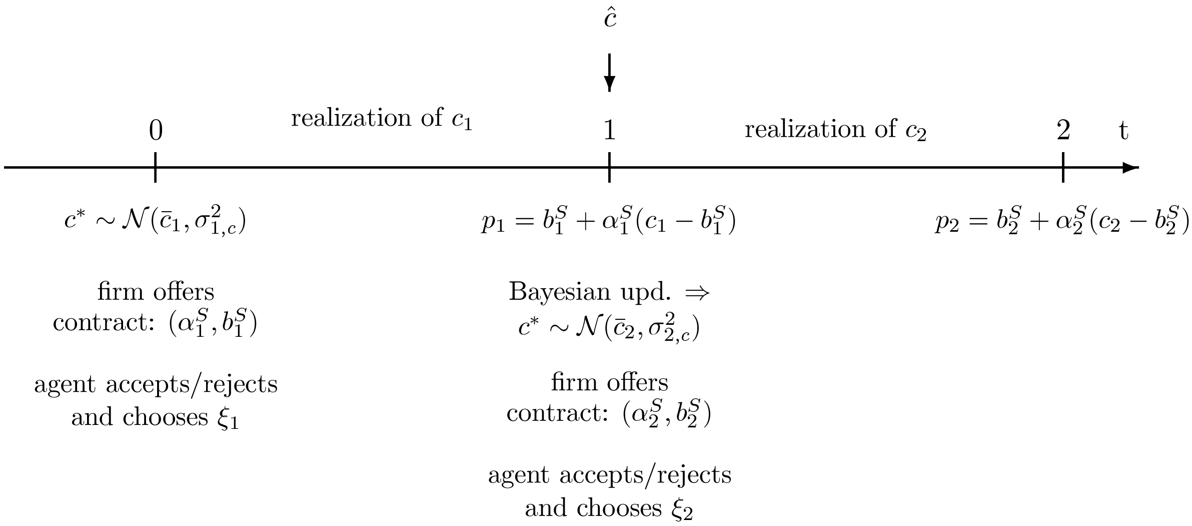
Figure 3: Comparison of the expected overall price in a long term relationship if a long term contract (solid line) or two short term contracts (bold line) are used.

Figure 4a: Optimal first period incentive rates depending on the precision of the additional signal for (i) short term contracts governing long term relationships (sparsely dotted line), (ii) short term relationships (dotted line), (iii) long term contracts (solid line) and (iv) renegotiation-proof long term contracts (thick line). ($\sigma_s^2 \in [0, 5], \delta = \lambda = \sigma_{1,c}^2 = \sigma^2 = 1$).

Figure 4b: Optimal second period incentive rates depending on the precision of the additional signal for (i) short term contracts governing long term relationships (sparsely dotted line), (ii) short term relationships (dotted line), (iii) long term contracts (solid line) and (iv) renegotiation-proof long term contracts (thick line). Note that the second period incentive rates in both types of short term contracts and the renegotiation proof long term contract coincide.

Figure 4c: Expected overall price for the manufacturing firm depending on the precision of the additional signal for (i) short term contracts governing long term relationships (sparsely dotted line), (ii) short term relationships (dotted line), (iii) long term contracts (solid line) and (iv) renegotiation-proof long term contracts (thick line).

Figure 1



$\hat{c}$
0
realization of c_1
1
realization of c_2
2
t
$c^* \sim \mathcal{N}(\bar{c}_1, \sigma^2_{1,c})$
$p_1 = b_1^S + \alpha_1^S(c_1 - b_1^S)$
$p_2 = b_2^S + \alpha_2^S(c_2 - b_2^S)$
firm offers contract: (α_1^S, b_1^S)
agent accepts/rejects and chooses ξ_1
Bayesian upd. $\Rightarrow$ $c^* \sim \mathcal{N}(\bar{c}_2, \sigma^2_{2,c})$
firm offers contract: (α_2^S, b_2^S)
agent accepts/rejects and chooses ξ_2

Figure 2

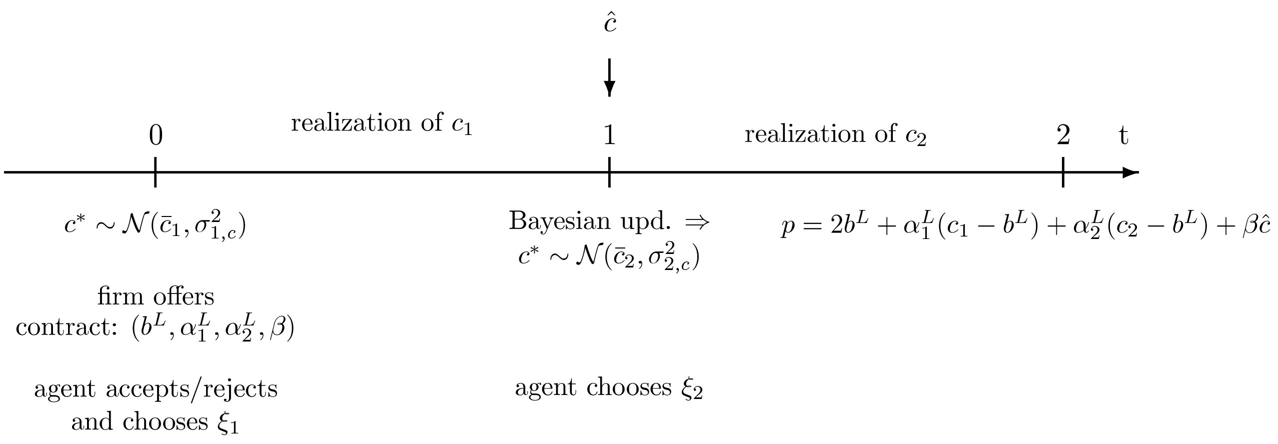

$\hat{c}$
0
realization of c_1
1
realization of c_2
2
t
$c^* \sim \mathcal{N}(\bar{c}_1, \sigma^2_{1,c})$
firm offers
contract: $(b^L, \alpha^L_1, \alpha^L_2, \beta)$
agent accepts/rejects
and chooses ξ_1
Bayesian upd. $\Rightarrow$
$c^* \sim \mathcal{N}(\bar{c}_2, \sigma^2_{2,c})$
agent chooses ξ_2
$p = 2b^L + \alpha^L_1(c_1 - b^L) + \alpha^L_2(c_2 - b^L) + \beta\hat{c}$

Figure 3

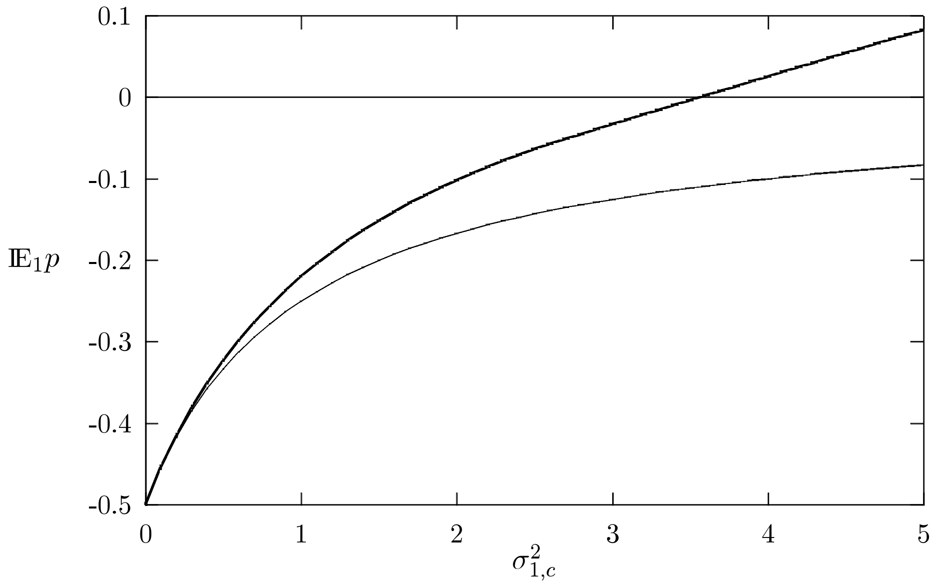


Figure 4a

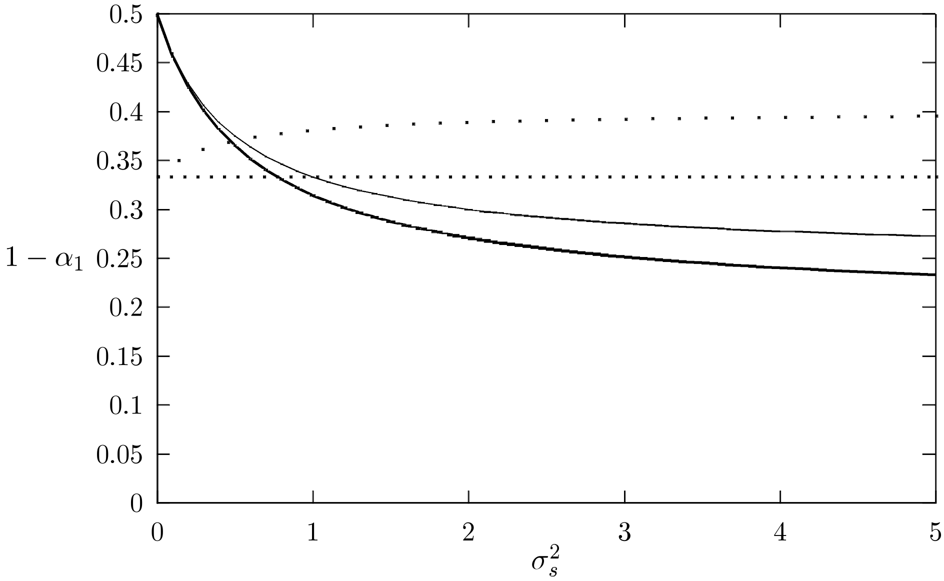


Figure 4b

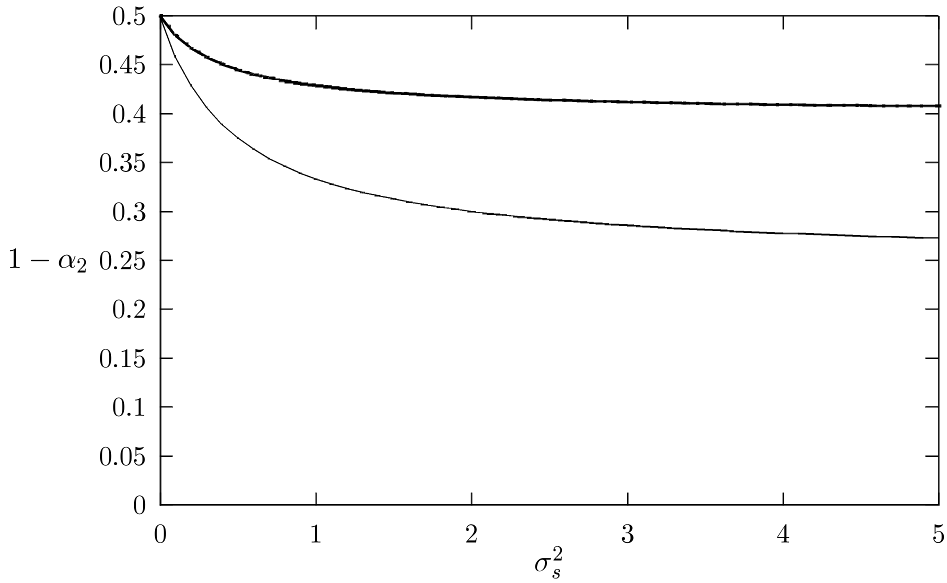


Figure 4c