The Hold-up Problem in Government Contracting

by

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Abstract

This paper considers a two-period procurement model in an incomplete-contract framework. In contrast to Hart-Moore (1988), the welfare-maximizing government, as buyer, is able to accomplish ex-ante optimal contracts which guarantee first-best specific investments of both buyer and seller. These contracts are precisely characterized. Regardless of the underlying supports of cost and benefit distributions renegotiation inevitably occurs in some states of nature. This renegotiation always increases the ex-ante fixed trade price. Hence, the empirical observation of soft budget constraints in government contracting can be rationalized. Furthermore, in accordance with common beliefs, the seller's rents accrue only at the production stage.

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I Introduction

It is a common belief that various inefficiencies are inherent when governments buy goods or services. One potential source of this belief are the price increases which are notoriously observed in large procurement programs. These post-contractual price adjustments are often claimed to result from commitment failures which are seen as a specific feature of economic activities of the public hand. In this paper we challenge these common beliefs. Instead, we show in a theoretical model that there is a rationale in the upward renegotiation of contracted prices in public procurement. Clearly, when standard goods are bought by governments, there is no justification for a deviation from initial contract terms. In many cases, however, the government does not simply buy standardized goods which are part of the usual supply of the private firm with whom the government makes a contract, but rather specific goods whose technology is (at least partly) unknown at the date the project is started. These sophisticated projects are the focus of our analysis. Procurement in these cases can be characterized as a two-step process consisting of innovation and production. The goods can only be supplied if, prior to production, the private contractor engages in specific innovative activities, for instance in the development of a new hospital technology or the special design of a particular building for child care or for elderly handicapped people. Hence, innovation is the first part of the contractual relationship between government and a private firm; production and trade are the second part. The innovative effort of the private supplier is relationship-specific, at least to a great extent: special technological innovations which are useful in constructing a particle accelerator of a government research institution are practically worthless if the project is not completed.

In addition, while preparing a procurement project the government also has to perform specific investment expenditures for complementary goods which are essential in ensuring the success of the project. For example, one can think of investment in infrastructure when a new hospital or a new university campus is to be built, the government employment of scientific specialists if the above-mentioned particle accelerator is projected, etc.

Any sort of government procurement has much to learn from experiences in military procurement. This is an area with eminent importance of relationship-specific innovations. Many technological developments which are useful in constructing defense equipment can only be used when purveying for the public hand. Government's development of a particular radar system to increase the value of a fighter aircraft project has a negligibly low market value if the project does not pass the blue-print stage. The recent practice of the US Department of Defense has switched from cost-plus to fix-price contracts for innovations (Kovacic,1991). The same policy can be recommended for any form of procurement, as shown by the first-best result of this paper.

Typically, the relationship between the government and the firm during the initial innovation phase is governed by an incomplete contract. The reasons for ex-ante contract incompleteness can easily be isolated : since both the amount of the parties' specific investments is nonverifiable and contracts cannot be made contingent on costs or gross welfare, there is room only for very rough contracts to be written at the ex-ante stage. In the case of private procurement, according to Williamson (1985) in such a setting a hold-up problem arises. Since the division of the net surplus from trade cannot be fixed ex-ante, the parties cannot be prevented from renegotiating the initial contract terms when the net value of the project finally has become clear. Since, however, the specific investments are sunk at this date, they do not influence the outcome of the renegotiations. Accordingly, since the investments cannot be protected by an ex-ante contract, the respective investor anticipates his exploitation and underinvests in relationship-specific assets.

In their seminal paper, Hart and Moore (1988) presented a formal analysis of the hold-up problem in a model where one unit of a homogeneous good may be traded between a private seller and a private buyer who both engage in relationship-specific investments prior to production[1]. Assuming that contracts are incomplete, they concluded that a first-best outcome cannot be achieved because the specific investments will not be chosen optimally. As the subsequent literature showed, the crucial point driving their inefficiency result is the assumption that only 'at will' - contracts can be written at the beginning of the relationship. This means that, in case of legal disputes between the parties, the court is unable to decide which party is responsible for an eventual breach of the initial contract. Of course, the court observes whether the project has been cancelled, but it cannot assign the responsibility for that event to any one party. Accordingly, the inclusion of breach penalties into the initial contract is infeasible; the completion of the project after the initial innovation phase is a voluntary decision of both agents.

By deviating from this decisive assumption, other authors arrived at a first-best result. Chung (1991) and Aghion, Dewatripont and Rey (1994) showed that for variable quantities a first-best result can be attained if 'specific performance' - contracts are available, that is if the trade of a positive quantity can be enforced by the court in the case of disagreement between the parties. Assigning an adequately chosen default option to one player and making the other player residual claimant

[1] Tirole (1986) analyzed a procurement model of a similar spirit; however, in the main part of his paper he assumes asymmetric information between the actors and contracts which are even more incomplete than those in Hart-Moore. He always arrives at an over- or underinvestment result.

in renegotiations[2], both players are given the right incentives to invest efficiently. Nöldeke and Schmidt (1995) further strengthened the Chung/Aghion-Dewatripont-Rey result by considering the original indivisible-good setting. They allow for 'option contracts' under which one party unilaterally can insist on trade. Thereby, a first-best result is achieved. If renegotiations occur in their model, a renegotiation game of the Hart-Moore style is employed where (endogenously) all bargaining power rests with the buyer.

In contrast to Hart-Moore, the above-mentioned papers share the assumption that a court can verify who is guilty for not trading in the case of an ex-post cancellation of the project. Implicitly, this approach expresses the view that the exact nature of the good at stake is known and verifiable at the beginning of the relationship since otherwise the seller would be free to deliver some different (and cheap) good to the buyer who would be unable to reject the delivery. The Hart-Moore voluntary trade assumption, however, fits into a setting where the precise design of the project is not quite clear at the starting date. In our paper, we will stick to the Hart-Moore assumption of at-will contracting as this modelling is most natural in our context.

Since this paper is on public procurement, in contrast to the other papers on the hold-up problem we deal with a buyer who is a government agency and is interested in maximizing welfare. The seller is a private contractor who maximizes profit. In the main part of the paper, we will assume an environment which is characterized by negligible shadow costs of public funds. Under this assumption, we will show that by means of an appropriately chosen ex-ante contract the first best can be achieved. Moreover, our result carries over to the case of significant shadow costs if the government ex ante can commit not to distort the supplier's ex-post profits. This requirement means that the shadow costs of the seller's ex-post realized profits do not influence the government's investment behavior and its consent to trade. This commitment device is in line with the results of Rogerson's (1989) empirical study of defense companies which compete for the production stage of procurement projects. The author claims that the overall profit of the supplier should be reduced to zero, but this does not necessarily require zero profit at each step of the procurement process: 'In fact, the major theoretical point [...] is that there is a very good reason to structure the regulatory process so that negative economic profit is earned in the innovative phase and positive profit is earned in the production phase.'

If such a commitment is not feasible, efficient investments in general cannot be attained: whatever initial contract has been written, the government has an incentive to reduce the ex-post rents of the seller by lowering the probability of final trade, that is by reducing its own specific investments. Accordingly, if significant shadow

[2]This is an assumption in Chung. It results from the renegotiation design which is modelled in Aghion-Dewatripont-Rey.

costs and a commitment failure jointly occur, both-sided efficient investments cannot be supported in the subgame-perfect equilibrium. This result implies that in contrast to common beliefs [3], optimal government behavior in procurement should be characterized by soft renegotiation behavior.

Under commitment or vanishing shadow costs, the optimal ex-ante contract induces a fundamental dichotomy: if it is ex-ante clear that the subsequent benefits of the project will always exceed its costs, the optimal contract has to set a trade price which will never induce renegotiation; if, however, the buyer and the seller know that with certain probability the benefit of the project may fall below its costs, then it is never optimal to fully exclude the possibility of renegotiation. If renegotiation actually occurs in such a case, it leads to an ex-post trade price in excess of the ex-ante price. Moreover, we will prove that upward renegotiation is not only a casual feature under the optimal contract, but that there is a positive probability of renegotiation under the optimal contract in any possible setting.

Our upward-renegotiation result is opposite to the outcome of Hart-Moore for the case of one-sided investments of the seller [4]: in their setting, ex-ante prices must be chosen in such a way that the first-best outcome requires a downward renegotiation of the ex-ante contracted trade price in every state of the world [5]. The difference is due to the fact that the seller can only be made residual claimant for his cost savings, if he receives the social value of the relationship in every state of the world. In private contracting under the Hart-Moore renegotiation game, which assigns the bargaining power to the party which agrees to efficient trade under the initial prices, this can only be ensured if the ex-ante trade price is chosen so high that the buyer always refuses delivery unless there is downward renegotiation. In contrast, since in our framework the government always agrees to trade if this is efficient, downward renegotiation is no matter of concern.

Summarizing, the negative evaluation of soft budget constraints must be challenged: in our setting soft budget constraints, that is the abandonment of ex-ante fixed prices in combination with a soft renegotiation behavior in the case of significant shadow

[3]Tirole (1992), for example, proposes a split-up uf government institutions. In his model a regulated public firm must sink specific investments in order to increase a project's value. The firm will not invest since it anticipates a too soft behavior of a monolithic benevolent government ex-post. If, on the other hand, the final decision on the completion of the project is taken by a finance ministry which observes only a monetary fraction of total benefits, the government's budget constraint can be hardened. This has a positive effect on the firm's ex-ante investments.

[4]Note that our model in some sense corresponds to the one-sided investment case of Hart-Moore (1988), Proposition 3, case (2), since the government will always invest efficiently, given its welfare-maximizing behavior.

[5]Nöldeke-Schmidt arrive at renegotiation cases in which either the trade price or the non-trade price is increased.

costs, appear as a necessary prerequisite for obtaining the first-best outcome. [6]
The paper is organized as follows. In section II we present the model, in particular the sequence of events. In section III we shall deal with a simple example which helps to lay out explicitly the game in a simplified version. In section IV, the general version of our model is presented and solved; moreover, we shortly deal with the implementation of the optimal contract from the government's viewpoint. A brief conclusion follows.

II The Model

II.1 The Stages of the Game

The two actors of our model are a procurement agency and a private contractor. The private contractor is to be chosen by means of some bidding process or maybe is directly chosen by the procurement agency who knows that he is the only potential supplier[7]. Both agency and contractor are risk neutral. At all stages of the game both actors have symmetric information: each actor observes the levels of both relationship-specific investments as soon as they are made; both actors simultaneously learn nature's move determining value and costs of the project. In order to lay the game structure open, we illustrate the sequence of events in the subsequent Figure 1.

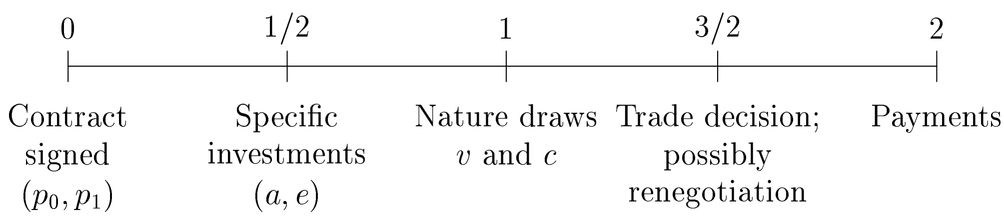

Abbildung 1: Game structure

At *date 0* the actors write a contract which governs their complete future relationship concerning the trade of one unit of an indivisible good (in the following called the 'project'). This contract is incomplete. Although we consider a multi-stage game with observed actions, a third party - the court - can only observe whether there has been trade and whether the corresponding payments have been made. This

[6]This is in sharp contrast to the informal literature of the subject. In the defense procurement context Kovacic (1991), for example, judges renegotiation as a major weakness of fix-price contracts.
[7]For details of the selection process, see fn.23 below.

assumption is fully in line with the usual motivation for incomplete contracts. An outsider like the court can hardly verify the benefits and costs of the project: the benefits are rather subjective in nature and - even if complete accounting data are available - the firm cannot be prevented from shifting costs between different activities. Hence, if the project is not completed ex-post, the court cannot assign the responsibility for the breach of the contract to any one party. Accordingly, the ex-ante contract can only be conditioned on the ex-post verifiable events 'trade' or 'no trade' and on the ex-post verifiable payment of the government.

Let $q = 1$ or 0 be the quantity to be traded. For these two cases prices p_1 and p_0, respectively, are fixed in the contract:

$$q = 1 \iff p = p_1, \tag{1}$$

$$q = 0 \iff p = p_0. \tag{2}$$

In the no-trade case the private contractor will receive some price p_0 which can be interpreted as a cancellation fee or a reward for his relationship-specific effort [8]. In the trade case, he will receive p_1 which pays for both the costs of the specific investment and the costs of the subsequent completion of the project at stake. Alternatively, one can think of p_0 as the reward for innovation and $(p_1 - p_0)$ as the reward for production.

After signing the contract, the procurement agency and the private contractor en gage in relationship-specific investments, say at *date 1/2*. We denote the government's investments by a and the investments of the firm by e. The investment levels are commonly observed by the two parties, but are not verifiable before a court. The associated expenditures are assumed to be convex in the arguments and written as $\mu(a)$ and $\psi(e)$.

At *date 1*, the state of the world $\omega \in \Omega$ is drawn by nature and both agents come to know the realized values of benefits and costs. We denote v as the procurement agency's valuation of benefits and c as the private contractor's project completion costs. Both values refer to one unit of the relevant good, the project. They will accrue at date 2 if and only if trade takes place and the firm completes the project. We shall assume that nature draws (stochastically independent) realized values of benefits and costs from given sets of possible values, $\{v_i\}, i = 1, ..., I$, and $\{c_j\}, j = 1, ..., J$. According to nature's random draw, the values occur with conditional probabilities $\pi_i(a)$ and $\rho_j(e)$, where the probabilities depend on the agents' investments. Higher a increases the probability of a higher value of the project, higher e increases the probability of lower costs.

[8] As we shall see, however, in equilibrium p_0 can take a negative value. This can occur in particular if the relative value of the seller's specific investments is low as compared with the completion costs .

Between *date 1* and *date 2* the final decision on the completion of the project has to be taken, say at *date 3/2*. At this date, renegotiations between the parties on the contractual terms are possible. We assume that only the procurement agency has the right to open renegotiations and hence the agency has all the bargaining power. This treatment of the government as a Stackelberg leader makes it possible to forgo the explicit modelling of the renegotiation process since this is not the focus of our work. Note, however, that this explicit assumption on the distribution of bargaining power is only made for convenience. It results endogenously if we employ a renegotiation game of the Hart-Moore (1988) type, as long as messages cannot be verified[9]. Moreover, note that none of the results of this paper is sensitive to the distribution of ex-post bargaining power. We denote by p^T the final trade price (which can be p_1 or a renegotiated price).
At *date 2*, finally, the physical completion of the project takes place (if agreed upon) and the corresponding payments are provided.

II.2 Setup and First-best Benchmark

The procurement agency is a welfare maximizer. We assume that it has a lexicographic preference ordering with respect to allocative efficiency and payments. This modelling is equivalent to assuming an objective function reflecting costs of raising public funds λ (see Laffont-Tirole (1993)) where $\lambda \to 0$. As argued in the introduction, introducing significant shadow costs does not influence our results qualitatively if the government agency can commit to ignore the shadow costs of the firm's profits after the initial contract has been written. Since a welfare-maximizing government would always prefer such a commitment, in some sense our approach reflects a long-term benevolence assumption of government behavior. While it could save on expenditures in certain states of nature by distorting the seller's ex-post rents, such a behavior would be short-sighted from a welfare point of view since investment incentives are undermined. For an analysis of signicant shadow costs under commitment and non-commitment, see appendix 1.
When the final trade decision has to be taken, the agency will only care for allocative efficiency. If trade is efficient but the supplier credibly refuses trade under the initial terms of contract, however, the agency uses its bargaining power in order to ensure the lowest possible trade price. By a slight abuse of notation[10], the agency's objective

[9]In an alternative setting, the full bargaining power of the government also arises in a changing-offers sequential-bargaining game. If the supplier at date 1 has to pay a certain amount of money (a 'hostage') to the government which is repaid without interest when the final trade decision has been taken (see Aghion-Dewatripont-Rey (1994)), by an appropriate choice of this hostage the buyer's full bargaining power is attained.

[10]For a precise formulation of the government agency's utility function, one must define $G =$

function is

$$\mathcal{W} = \begin{cases} \mathcal{E}_{\omega|(e,a)}\{v_i - c_j | q = 1\} - \mu(a) - \psi(e) & \text{at dates } 0,\ 1/2, \\ q(v_i - c_j) & \text{at date } 3/2, \end{cases} \quad (3)$$

where the expectation operator refers to states of the world, conditional on the parties' specific investments. Considering the expectation operator implies that the application of the trade rule (i.e. the subgame-perfect continuation of the game) is internalized.

The private contractor maximizes expected profit

$$\Pi = \begin{cases} \mathcal{E}_{\omega|(e,a)}\{p^T - p_0 - c_j | q = 1\} + p_0 - \psi(e) & \text{at dates } 0,\ 1/2, \\ q(p^T - p_0 - c_j) + p_0 & \text{at date } 3/2, \end{cases} \quad (4)$$

where p^T is the realized trade price, that is either the ex-ante contracted price p_1 or the modified price resulting from ex-post renegotiations. Note that the supplier's participation constraint requires Π to be nonnegative at date 0.

For later reference, we derive the first-best benchmark which requires two notions of efficiency. First, *ex-post efficiency* refers to the trade rule of the model, that is to the decisions made at date 3/2 . It requires trade to take place iff this increases welfare, that is

$$q^* = 1 \Longleftrightarrow \quad v_i \quad \geq c_j, \quad (5)$$

$$q^* = 0 \Longleftrightarrow \quad v_i \quad < c_j. \quad (6)$$

Ex-ante efficiency refers to the optimal choice of the specific investments a and e, that is, to decisions at date 1/2:

$$(a^*, e^*) \in argmax_{a,e}\ \mathcal{W} = \quad \mathcal{E}_{\omega|(e,a)}\{v_i - c_j | q^* = 1\} - \mu(a) - \psi(e). \quad (7)$$

a^* and e^* are used as a benchmark to be compared with the actual choice of investments resulting from the two actors' investment game at stage 1/2. We assume that there is a unique solution of the benchmark model [11]. This solution can be described by two first-order conditions which are necessary and sufficient for an interior solution $a^*, e^* > 0$.

In the subgame-perfect equilibrium of the game between agency and seller, a *first-best result* is attained if at date 0 the production reward $(p_1 - p_0)$ can be chosen

$G(x, y)$, where x denotes the level of allocative efficiency and y the payments to the firm. In this formulation, lexicographic preferences over these two arguments can be expressed as follows: $G > \tilde{G} \Longleftrightarrow$ (a) $x = \tilde{x}$ and $y < \tilde{y}$ or (b) $x > \tilde{x}$.

[11] Technically, the existence of an interior solution is ensured since expected welfare as defined in (7) is concave in both of its arguments and the Inada-conditions are assumed to be fulfilled. The maximum is unique if one assumes $|\mathcal{W}_{ii}| > |\mathcal{W}_{ij}|, i, j \in \{a, e\}$.

so as to induce both ex-ante and ex-post efficiency in the framework of our model. Note that by arbitrary choices of the absolute values of p_0 (or p_1, alternatively) any distribution of ex-ante utilities of the parties can be achieved; in particular, the ex-ante profits of the firm can be reduced to zero.

III A Simple Example

In order to provide a more intuitive flavor of the general results which will be stated in section IV, we start with a simple example. In this example we assume that there are only two possible realizations of benefits and of costs,

$$v \in \{\bar{v}, \underline{v}\}; \quad c \in \{\bar{c}, \underline{c}\}, \tag{8}$$

with $\bar{v} > \bar{c} > \underline{v} > \underline{c}$. Nature decides at date 1 which realizations occur; in our simple setting this can most easily be modelled by assuming probabilities

$$\pi(a) = prob\{v = \bar{v}|a\}; \quad \pi' > 0, \quad \pi'' \leq 0, \tag{9}$$

$$\rho(e) = prob\{c = \underline{c}|e\}; \quad \rho' > 0, \quad \rho'' \leq 0. \tag{10}$$

Higher investments increase the probability of low costs and of high benefits, respectively. In the following we are looking for the subgame-perfect equilibrium of the game under consideration. Hence, we employ backward induction in order to show that the equilibrium corresponds to the first-best result.

III.1 Ex-post Efficiency

We are interested in ex-post efficiency and in ex-ante efficiency. Solving the model by backward induction, we begin with the question of ex-post efficiency[12]. Ex-post efficiency requires the completion of the project if and only if the project's ex-post net value is positive, that is $v - c \geq 0$. Since at date 3/2 we consider a (constrained) bargaining game under symmetric information between the parties, achieving ex-post efficiency in the game is no serious matter of concern. Due to its welfare objective, the government regardless of contracted prices always agrees to trade if this is efficient. The firm, on the other hand, is willing to trade under the initial prices iff $p_1 - c > p_0$, that is, when its net payoff under trade exceeds its default option. If trade is efficient but this inequality does not hold, it is rational for the procurement agency to offer a new increased trade price $p^T = p_0 + c$ which makes the firm just indifferent between trade and no trade[13]. In the subgame-perfect

[12] For a more accurate representation of this stage of the game, see subsection IV.1 below.

[13] Recall the lexicographic preference ordering of the government, subsection II.2 above.

equilibrium, the firm accepts this offer and the project is completed. As we see, ex-post efficiency is attained, if necessary through renegotiations.

III.2 Ex-ante Efficiency

Let us next turn to the problem of ex-ante efficiency. Given the subgame-perfect continuation of the game (at date 3/2) which has been characterized in the subsection above, our program is to derive the Nash-equilibrium at date 1/2, where the two actors choose their equilibrium investment levels for a fixed price tuple (p_0, p_1). After calculating this equilibrium, we ask if there are optimal prices to be implemented at date 0 which induce a first-best result, that is efficient investment levels (as we have seen, ex-post efficiency is not hard to derive).

For reasons of comparison, we therefore first formulate a benchmark model in which a social planner maximizes welfare with respect to a and e. The planner faces the same veil of uncertainty about the subsequent states of the world as the procurement agency and the private contractor. We obtain the following maximization problem:

$$\begin{aligned} \text{maximize}_{a,e} \quad \mathcal{E} & \quad \{v - c | q^* = 1\} - \mu(a) - \psi(e) \\ = & \quad \rho(e)\pi(a)[\bar{v} - \underline{c}] + (1 - \rho(e))\pi(a)[\bar{v} - \bar{c}] \\ + & \quad \rho(e)(1 - \pi(a))[\underline{v} - \underline{c}] - \mu(a) - \psi(e). \end{aligned} \tag{11}$$

We assume the existence of a unique interior solution[14], which is described by

$$\rho'(e^*)[\underline{v}(1 - \pi(a^*)) + \pi(a^*)\bar{c} - \underline{c}] = \psi'(e^*), \tag{12}$$

$$\pi'(a^*)[\bar{v} - (1 - \rho(e^*))\bar{c} - \rho(e^*)\underline{v}] = \mu'(a^*). \tag{13}$$

The outcome of the benchmark model has to be compared with the Nash equilibrium of the procurement agency and the private contractor resulting from their respective maximizations at date 1/2. The agency is a welfare maximizer. Its optimization problem is as follows:

$$\text{maximize}_a \quad \mathcal{E}\{v - c | q^* = 1\} - \mu(a) - \psi(e). \tag{14}$$

Since we deal with a Nash equilibrium, this welfare-optimization problem is solved for given private investments e. Therefore, ex-ante efficiency will be achieved if and only if the private firm chooses a welfare-optimal investment level.
When will this be the case? At date 1/2, the private contractor is interested in maximizing his expected profit as explicitly explained in subsection II.2 above,

$$\begin{aligned} \Pi & = \mathcal{E}\{p^T - p_0 - c | q^* = 1\} + p_0 - \psi(e) \\ & = \pi(a)\rho(e)[p^T - p_0 - \underline{c}] + \pi(a)(1 - \rho(e))[p^T - p_0 - \bar{c}] \\ & \quad + (1 - \pi(a))\rho(e)[p^T - p_0 - \underline{c}] + p_0 - \psi(e), \end{aligned} \tag{15}$$

[14] See footnote 11 above.

where the prices have been fixed at date 0. In order to facilitate the solution of the problem, we proceed by transforming (15) into a more tractable form. First, let us show that $(p_1 - p_0)^* > \underline{c}$ is necessary in order to attain positive incentives for the seller's investments. Suppose not: In this case the firm would always receive a net payoff of p_0, either because there is no trade or because it receives a trade price $p^T = p_0 + c$ which also guarantees a net payment of p_0. However, if the firm receives p_0, regardless of whether it invests or not, it will always choose $e = 0$ in order to minimize investment costs $\psi(e)$. Since ex-ante efficiency requires a positive investment, $(p_1 - p_0)^* > \underline{c}$ follows immediately. Given the above reasoning, we can rewrite the private contractor's expected profit in the following way:

$$\begin{aligned} \Pi = \pi(a)\rho(e)[p_1 - p_0 - \underline{c}] + \pi(a)(1 - \rho(e))[p^T(\bar{c}) - p_0 - \bar{c}] \\ +(1 - \pi(a))\rho(e)[p_1 - p_0 - \underline{c}] + p_0 - \psi(e), \end{aligned} \tag{16}$$

where p^T in (16) has been replaced by p_1 in the low-cost case and by $p^T(\bar{c})$ in the high-cost case. The private firm will participate in the innovation process if the expected profit (16) is non-negative. Hence, the participation constraint requires $\Pi \geq 0$ at date 0. If this constraint is fulfilled, the private contractor will maximize expected profits with respect to investments e. This leads to the following first-order condition:

$$\rho'(e)[p_1 - p_0 - \underline{c} - \pi(a)(p^T(\bar{c}) - p_0 - \bar{c})] = \psi'(e). \tag{17}$$

The resulting investment is not necessarily welfare-optimal. Whether a welfare-optimal private investment is achieved depends on the price difference $(p_1 - p_0)$. It is easy to show that the chosen investment level of the firm is unique (for any government agency's investment level a) and is a strictly positive function of this contracted price difference. Therefore, we have to ask whether there is an optimal ex-ante contracted price tuple that fulfills both the benchmark first-order condition (12) and the Nash-equilibrium condition (17). Equating the terms in brackets in (12) and (17), we obtain that welfare-optimal investments are guaranteed if the prices (p_0, p_1) are chosen according to

$$p_1 - p_0 - \pi(a^*)(p^T(\bar{c}) - p_0) = \underline{v}(1 - \pi(a^*)). \tag{18}$$

Let us now characterize $p^T(\bar{c})$: suppose that $(p_1 - p_0)^* > \bar{c}$ which would imply that renegotiations never occur under the optimal solution, even in the high-cost state. In this case equation (18) could be written as

$$(p_1 - p_0)(1 - \pi(a^*)) = \underline{v}(1 - \pi(a^*)) \quad \Longleftrightarrow \quad (p_1 - p_0) = \underline{v}, \tag{19}$$

which yields a contradiction to the assumption $(p_1 - p_0)^* > \bar{c}$. Hence, renegotiation necessarily occurs in the high-cost state; accordingly, $p^T(\bar{c}) = p_0 + \bar{c}$ and the welfare-optimal price tuple is characterized by

$$(p_1 - p_0)^* = \underline{v}(1 - \pi(a^*)) + \pi(a^*)\bar{c}. \tag{20}$$

It can directly be seen from (20) that $\underline{v} < (p_1 - p_0)^* < \bar{c}$. The first-best price tuple is chosen in such a way that renegotiation is anticipated for the case of $(\bar{v}, \bar{c})$. This renegotiation leads to a trade price $p^T = p_0 + \bar{c}$ which is higher than originally contracted. Note that the firm derives no rents when nature draws high project-completion costs whereas in the case of low costs it receives a positive 'production rent' $\underline{v}(1 - \pi(a^*)) + \pi(a^*)\bar{c} - \underline{c}$.

Summarizing, we have shown that in our simple setting there is a unique contract $(p_1 - p_0)^*$ which induces efficient specific investments of both actors. Moreover, ex-post efficiency (trade iff $v \geq c$) is achieved, if necessary by renegotiation. Since ex-ante and ex-post efficiency are achieved, a first-best result is obtained. The first-best price tuple necessarily features the occurence of renegotiations in some states of nature. If renegotiation occurs, it always leads to a higher trade price than originally contracted. This justifies soft budget constraints as a rational government policy.

IV The General Model

In this section, we will provide a general characterization of the ex-ante optimal contract. As we will show, the upward-renegotiation result of the preceding example carries over to any arbitrary choice of parameters. While it is not hard to see why any renegotiation will result in an upward renegotiation of the initial trade price, it remains to show that renegotiation necessarily must occur in any possible setting, which means that the optimal price differential is characterized by $(p_1 - p_0)^* < \bar{c}$. Instead of only two realizations of benefits and costs, let us now assume many possible realizations which can be ordered as follows:

$$\underline{v} = v_1 < ... < v_i < ... < v_I = \bar{v}; \qquad I \geq 2, \tag{21}$$

$$\bar{c} = c_1 > ... > c_j > ... > c_J = \underline{c}; \qquad J \geq 2. \tag{22}$$

At date 1 nature draws the realized values v_i and c_j from the above lists of deterministic variables. The probability that a particular v_i or c_j is drawn depends on the respective investments which, for convenience, are normalized to the zero-one interval. Following Hart and Moore (1988) we specify probabilities of v_i and c_j, respectively:

$$\pi_i(a) = a\pi_i^+ + (1 - a)\pi_i^-, \tag{23}$$

$$\rho_j(e) = e\rho_j^+ + (1 - e)\rho_j^-. \tag{24}$$

Here π^+ and π^- are probability distributions over $(v_1, ..., v_I)$ and π_i^+/π_i^- is increasing in i (monotone likelihood ratio property). Analogously, ρ^+ and ρ^- are probability distributions over $(c_1, ..., c_J)$ and ρ_j^+/ρ_j^- is increasing in j. Moreover, in order to guarantee unique interior solutions, we assume the investment cost functions to be concave in their arguments and $\psi(0) = \mu(0) = \psi'(0) = \mu'(0) = 0, \psi'(1) = \mu'(1) = \infty$. According to the Linear-Distributions-Function Condition (LDFC) presented in (23) and (24), a particular choice of investment determines a linear combination of two probability distributions, for instance π^+, π^-. Because of the monotone likelihood ratios (which imply first-order stochastic dominance) both actors prefer the 'better' distribution (π^+, ρ^+) which they achieve more easily by higher investment. This implies that higher investments increase expected utility and reduce expected costs, respectively. Note that the second derivatives of the probabilities $\pi_i(a), \rho_j(e)$ vanish since the LDFC is characterized by constant first derivatives

$$\pi_i' = \pi_i^+ - \pi_i^-, \tag{25}$$

$$\rho_j' = \rho_j^+ - \rho_j^-. \tag{26}$$

For later reference, note that $\sum_{j=1,...,J} \rho_j' = \sum_{i=1,...,I} \pi_i' = 0$.

IV.1 Ex-post Efficiency

In this subsection we show that at date 3/2 a positive decision on project completion is taken by the actors if trade is efficient, that is if and only if $v_i \geq c_j$ given any realizations v_i and c_j. Furthermore, we argue that the only possible renegotiations refer to an increase of the initially contracted trade price. Consider the parties' objectives: the government trades only if this is efficient and it cannot be induced to an inefficient trade by the seller's offering a lower price than originally contracted. The profit-maximizing seller, on the other hand, credibly will reject trade if this diminishes his ex-post profit as compared to his default option payoff p_0. In this case, if trade is efficient, the government will use its power to open renegotiations and will offer a new trade price p^T which makes the firm just indifferent between trade and no trade. (The agency will not offer a higher trade price because of its lexicographic preference ordering.) Hence, the following cases can be distinguished[15]:

(a) if $v_i < c_j$, the firm receives p_0 because the government agency does not agree to trade $(q = 0, p = p_0)$.

(b) if $v_i \geq c_j$ and $p_1 - p_0 \geq c_j$, there is trade without renegotiation and the private contractor receives p_1 $(q = 1, p = p^T = p_1)$.

[15] This distinction is our counterpart to proposition 1 in Hart-Moore (1988).

(c) if $v_i \geq c_j$ and $p_1 - p_0 < c_j$, there is trade only after renegotiation; in this case, the government agency offers a trade price $p_0 + c_j$ under which the firm (weakly) agrees to trade ($q = 1, p = p^T = p_0 + c_j$).

In all of these cases, ex-post efficiency is obtained, in case (c) via renegotiation. Because of the Coase theorem, one should have expected ex-post efficiency as we deal with a (constrained) bargaining game under complete information. The specific result of only upward renegotiation, however, rests on our welfare-maximizing buyer setting[16].

IV.2 Ex-ante Efficiency

We now examine date 1/2 and consider the investment choices at given prices (p_0, p_1). Since the procurement agency maximizes welfare, we can forgo the explicit presentation of its optimization. Given first-best effort of the private contractor, in a Nash equilibrium it will choose its investments in such a way that ex-ante efficiency is obtained.

Hence, the main problem is the achievement of the welfare-optimal e^* of the private contractor. For this purpose we start from the private firm's maximization problem

$$\text{maximize}_e \quad \sum_i \sum_{\substack{j \\ v_i \geq c_j}} \pi_i(a)\rho_j(e) max\{p_1 - p_0 - c_j, 0\} + p_0 - \psi(e). \tag{27}$$

Note that (27) is twice continuously differentiable and concave in e. Given our assumptions, this optimization [17] leads to the following necessary and sufficient first-order conditions for a unique maximum:

$$\sum_i \sum_{\substack{j \\ v_i \geq c_j}} \pi_i(a)\rho_j' max\{p_1 - p_0 - c_j, 0\} = \psi'(e^N) \quad \forall a. \tag{28}$$

One can show that the Nash equilibrium investment $e^N = \tilde{e}(a, p_1 - p_0)$ for each a is strictly increasing in its second argument, the price difference $(p_1 - p_0)$. Note that only this price difference is relevant for the investment equilibrium level; the absolute values of both prices are irrelevant in this respect.

[16] Of course, our specification of the trade price is due to our simplifying assumption that the government holds the full bargaining power in renegotiations. This assumption, however, is in no way decisive for the qualitative analysis of the bargaining process. Under any possible assumptions on the bargaining strength of the parties there would be only an upward renegotiation of the initially contracted trade price.

[17] We assume that the participation constraint of the firm - nonnegative expected profits at date 0 - is fulfilled by an appropriate choice of p_0.

The resulting investment should be welfare-optimal. Hence, to achieve ex-ante efficiency, e^N must be equivalent to the first-best investments of the firm as obtained by derivation of the benchmark welfare function (7) with respect to e:

$$\sum_i \sum_{\substack{j \\ v_i \geq c_j}} \pi_i(a^*)\rho_j'(v_i - c_j) = \psi'(e^*). \tag{29}$$

Since $\psi(e)$ is monotonically increasing in e, a necessary and sufficient condition for achieving ex-ante efficiency in a Nash-equilibrium is a price difference $(p_1 - p_0)^*$ which equates the left-hand sides of (28) and (29), that is

$$\sum_i \sum_{\substack{j \\ v_i \geq c_j}} \pi_i(a^*)\rho_j'(v_i - c_j) = \sum_i \sum_{\substack{j \\ v_i \geq c_j}} \pi_i(a^*)\rho_j' max\{(p_1 - p_0)^* - c_j, 0\}. \tag{30}$$

Given this condition for first-best investments of the firm, the welfare-maximizing government agency will choose investments $a^N = a^*$, which supports (e^*, a^*) as a Nash-equilibrium. In the following we will use the efficiency condition (30) in order to provide a precise characterization of those production rewards $(p_1 - p_0)^*$ which induce a first best. For this purpose it is convenient to distinguish between the cases of overlapping and non-overlapping distributions of benefits and costs.

Let us start with the most interesting case and suppose the existence of overlapping distributions[18], that is, there is ex-ante uncertainty of the ex-post desirability of the project.
An optimal price difference exists and can be characterized as shown in the following two steps. In a first step (STEP 1) we show that there is a unique $(p_1 - p_0)^*$ which generates ex-ante efficiency. Subsequently (STEP 2), we will give priority to the proof of the most interesting peculiarity of the ex-ante efficient prices, namely that the optimal $(p_1 - p_0)^*$ never can exceed the highest possible production cost $\bar{c}$. Hence, the optimal contract inevitably features renegotiations in some states of nature. The explicit proof of another non-trivial property of the optimal production reward (namely $(p_1 - p_0)^* > \underline{v}$) has been relegated to an appendix which is sent to the reader on request.
STEP 1: (a^*, e^*) is a Nash-equilibrium of the game if there is an optimal price difference $(p_1 - p_0)^*$ which fulfills (30) given that $a = a^*$ has been chosen by the agency. Now consider the left-hand side (LHS) of equation (30). For any possible investment decision of the procurement agency, the LHS has a unique value which - due to the monotone likelihood ratio property - is a continuous and strictly increasing function of a. Given the welfare-optimal decision a^* of the government agency, the LHS of (30) has a positive constant value. Hence, we must find a production reward

[18]Formally, this case occurs if $\exists\, v_i, c_j, c_{j+1} : c_j < v_i < c_{j+1}$.

$(p_1 - p_0)^*$ for which the RHS is equal to this constant. First, note that for any a, in particular for a^*, the RHS is continuous and (by the MLRP) strictly increasing in the price difference $(p_1 - p_0)$ - although not everywhere differentiable[19]. Using monotonicity, in order to prove the existence of a unique optimal price difference we have to find values of $(p_1 - p_0)$ which lead to a RHS which falls short of, respectively exceeds, the LHS. We start by considering $(p_1 - p_0) = \underline{c}$. In this case $max\{p_1 - p_0 - c_j, 0\}$ can never be positive and we can conclude RHS $= 0 <$ LHS, that is, underinvestment occurs. Next, let us examine $(p_1 - p_0) = \bar{v}$. Since in this case $\bar{v} > \sum_i \pi_i(a) v_i$, RHS $>$ LHS and hence overinvestment results[20]. Obviously, from the intermediate-value theorem, there must be a unique $(p_1 - p_0)^*$ which ensures the identity (30) . Now we can state the following lemma:

Lemma 1

There is a unique price difference $(p_1 - p_0)^*$ which generates ex-ante efficiency.

The argument of step 1 is similar to the proof of Nöldeke-Schmidt's (1995) main proposition. Note, however, that due to their option-contract assumption they can directly infer that $(p_1 - p_0)^* < \bar{c}$ while lemma 1 provides the weaker statement $(p_1 - p_0)^* < \bar{v}$. In the following step 2, we will prove that indeed $(p_1 - p_0)^* < \bar{c}$ holds even in our setting.

STEP 2: We prove $(p_1 - p_0)^* < \bar{c}$ by contradiction. Suppose that $(p_1 - p_0) \geq \bar{c}$ which implies that the $max-$operator on the RHS can be neglected. Now add $\sum_i \sum_{\substack{j \\ v_i \geq c_j}} \pi_i(a^*)\rho_j' c_j$ to both sides of (30), and rewrite (30) as

$$\sum_i \sum_{\substack{j \\ v_i \geq c_j}} \pi_i(a^*)\rho_j' v_i \geq \sum_i \sum_{\substack{j \\ v_i \geq c_j}} \pi_i(a^*)\rho_j'(p_1 - p_0). \tag{31}$$

Consider an arbitrary benefit $v_{i'}$ drawn by nature. Now distinguish between two cases:

(i) $v_{i'} \geq \bar{c}$. In this case, for any possible cost realization c_j, production is efficient and hence will always occur. Since the changes in probabilities of cost realizations add up to zero if all possible c_j are taken into consideration, that is $\sum_{\substack{j=1,\ldots,J \\ v_{i'} \geq c_j}} \rho_j' = 0$, we can state

$$\sum_j \pi_{i'}(a^*)\rho_j' v_{i'} = \sum_j \pi_{i'}(a^*)\rho_j'(p_1 - p_0) = 0. \tag{32}$$

[19] The derivative of the RHS with respect to $(p_1 - p_0)$ has a finite number of jumps occuring when the $max-$operator becomes positive in one more event (i.e. when $(p_1 - p_0)$ passes the 'next' c_j).

[20] This also proves that $(p_1 - p_0)^* < \bar{v} < \bar{c}$ if the underlying overlapping distributions are characterized by $\bar{c} > \bar{v}$.

Clearly, what is valid for one particular $v_{i'}$, also holds for all other elements of the set $\{v_i : v_i \geq \bar{c}\}$. Summarizing, one can state that for all utility realizations which exceed the highest possible production costs, RHS and LHS of equation (32) have the same zero value.

(ii) Finally, we have to examine a typical element $v_{i'}$ of the complementary set $\{v_i : v_i < \bar{c}\}$. Recall that the LHS and the RHS of (31) differ only in the expressions v_i (LHS) and $p_1 - p_0$ (RHS). Since trade cannot be realized for all possible cost realizations, by the monotone likelihood-ratio assumption $\sum_{\substack{j=1,\dots,J \\ v_{i'} \geq c_j}} \rho'_j > 0$. This and our claim $p_1 - p_0 \geq \bar{c}[> v'_i]$, guarantee that for all elements $v_{i'}$ of the considered set the value of the RHS exceeds the corresponding value of the LHS.

The assumption of overlapping distributions ensures that both case (i) and case (ii) are to be considered when summing up over all possible realized benefits. Hence, for $(p_1 - p_0) \geq \bar{c}$ we have:

$$\sum_i \sum_{\substack{j \\ v_i \geq c_j}} \pi_i(a^*)\rho'_j v_i < \sum_i \sum_{\substack{j \\ v_i \geq c_j}} \pi_i(a^*)\rho'_j(p_1 - p_0). \tag{33}$$

This, however, is a contradiction to (31) and our claim $(p_1 - p_0)^* \geq \bar{c}$.
Hence, we can state the following proposition:

Proposition 1: *If the distributions of benefits and costs overlap, there is a unique ex-ante contracted production reward $(p_1 - p_0)^*$ implementing the first-best outcome. This optimal price difference is characterized by*

$$max\{\underline{c}, \underline{v}\} < (p_1 - p_0)^* < min\{\bar{c}, \bar{v}\}.$$

Proof: STEP 1 demonstrates the existence and uniqueness of the first-best production reward and characterizes $\underline{c} < (p_1 - p_0)^* < \bar{v}$. In STEP 2 the validity of $(p_1 - p_0)^* < \bar{c}$ is shown. The (tedious, but straightforward) proof of $(p_1 - p_0)^* > \underline{v}$ is sent to the reader on request. ⋄

Let us further characterize the optimal price difference in the case of non-overlapping distributions, that is if there is no ex-ante uncertainty of the ex-post completion of the project. Obviously, if $\bar{v} < \underline{c}$, from an ex-ante viewpoint the procurement project is not desirable and hence will never get started. The opposite case deserves more interest:

Proposition 2: *If $\underline{v} \geq \bar{c}$, there is a continuum of production rewards inducing a first-best result. They are characterized by $(p_1 - p_0)^* \geq \bar{c}$.*

Proof: Note that (ii) in STEP 2 can be ruled out. Furthermore, equation (32) holds for all possible combinations of v_i and c_j if and only if $(p_1 - p_0)^* \geq \bar{c}$. Hence, the efficiency condition (30) is satisfied for all values $(p_1 - p_0)^* \geq \bar{c}$. Finally, we must show that any $(p_1 - p_0) < \bar{c}$ does not establish a first-best result. To see this, one can easily show that by slightly reducing $(p_1 - p_0)$ below $\bar{c}$ the marginal utility of the firm to invest is reduced by $(-\sum_i \pi_i(a^*)\rho'_J((p_1 - p_0) - c_J) > 0$. Since we know from STEP 1 that e^N is monotonically increasing in $p_1 - p_0$, the result is established. ⋄

The following theorem combines the results and elaborates their economic content:

Theorem 1 *In government procurement, there is a solution to the hold-up problem entailing a basic dichotomy :*

(a) If there is no ex-ante uncertainty on project completion, the set of optimal contracts never induces renegotiation of the initial prices in any state of nature.

(b) Under ex-ante uncertainty, the unique optimal production reward features (i) renegotiation in some states of nature independently of the underlying cost and benefit distributions and (ii) this renegotiation always increases the ex-ante contracted trade price.

Hence, soft budget constraints in government contracting can be rationalized if there is a positive ex-ante probability of the project's shutdown.

The intuition for the no-uncertainty result should be clear. If the project is desirable in all states of the world ($\underline{v} \geq \bar{c}$), the indirect externality between the firm and the government agency caused by the uncertainty of project completion vanishes. Hence, the government can guarantee a welfare-optimal investment level of the firm by making it the residual claimant to its own cost savings in all states of the world. Since the government never insists on renegotiation if trade is efficient, such a contract clearly induces optimal investments.

In the uncertainty case, on the other hand, there is no such simple interpretation: obviously, one can imagine settings where renegotiation occurs in some states of nature. Our result is stronger, however, since it states that $(p_1 - p_0)^* < \bar{c}$ independent of the distribution and the values of benefits and costs [21]. Hence, in any possible setting with ex-ante uncertainty there is upward renegotiation in some states of nature. While it should be obvious (and is proven in step 1) that choosing a price differential as large as the highest benefit realization must lead to overinvestment of the seller - and accordingly $(p_1 - p_0)^*$ must be smaller than $\bar{v}$ - there is no immediate

[21] Note that this trivially must hold in the case of option contracts: since the seller is made the residual claimant to his cost savings in *every* state of the world, i.e. even in states where trade is not efficient, choosing a price differential as high as the highest cost realization must result in overinvestment.

intuition for our result. The reason is that for all benefits which exceed the highest possible costs the firm's incentives are independent of the price differential as long as no renegotiations occur, i.e. if $(p_1 - p_0) \geq \bar{c}$ is chosen. For lower benefit realizations, on the other hand, this choice would result in overinvestment since the actual costs enabling trade are lower than the price differential. Accordingly, our result follows. Finally, note that this characterization by no means depends on our assumption on the parties' ex-post bargaining strength; it would still hold if the firm had any degree of bargaining power [22].

It has been argued in the introduction that the government is interested in extracting the firm's expected rents when it starts a procurement project, as long as this is compatible with the realization of allocative efficiency by $(p_1 - p_0)^*$. If the supplier has no informational advantages over the government at the contracting date, $\Pi = 0$ and according to the definition of expected profit in our general model (equation (27)) the payment p_0 amounts to

$$p_0^* = \psi(e^*) - \sum_i \sum_{\substack{j \\ v_i > c_j}} \pi_i(a^*)\rho_j(e^*)max\{p_1 - p_0 - c_j, 0\}. \tag{34}$$

This shows that the no-trade price is lower than the relationship-specific investment costs. The far-right term in (34) expresses the expected 'production rent' earned by the firm. Hence, one can see immediately that the investment expenditure must exceed the optimal payment p_0. In extreme cases, when there are no setup-costs (such that the average innovation costs per unit of e are not downward-sloped in the relevant range), it can even take a negative value. It is not the innovation stage but the production stage which is profitable for the private contractor. If the procurement agency knows the supplier's investment-cost function $\psi(e)$ the implementation of this optimal price p_0^* creates no problem. If this does not hold, in general there will be a tradeoff between efficiency and rents [23].

Let us state a final interesting remark: as we have seen, under the optimal incentive scheme p_0^* does not cover the investment expenditures of the winning firm, if all

[22] Since in this case the firm's production rent would increase, the optimal ex-ante price difference $(p_1 - p_0)^*$ even had to be lower than under the assumption of full bargaining power of the government.

[23] Of course, all rents can be extracted if there is a continuum of potential suppliers. In a setting with a finite number of diverse bidders, however, it is impossible to extract all rents by the bidding process. In this case, for example, under a first-price sealed-bid auction each bidder's equilibrium bid coincides with the expected valuation of the next-efficient bidder. Hence, it is still the most efficient firm which becomes the goverment's contractor, but at the price of an informational rent. If the government did not have lexicographic preferences, in order to reduce this rent, it probably would be in its interest to distort the announced completion price $(p_1 - p_0|\theta)^*$ downwards for any than the most efficient type. For auctions in a complete-contracting setting see McAfee-McMillan (1987) and Riordan-Sappington (1987).

ex-ante rents can be extracted. This property of the optimal contract, however, prevents mimicking strategies of inefficient firms, at least when some portion of the investment expenditures can be verified by a court. Were there rents accruing at the innovation stage, inefficient firms could use a 'take the money and run'-strategy by submitting the lowest bids and becoming the government's contractor.

V Conclusion

In this paper we have shown that in a public-procurement model there exist incomplete contracts which implement the first best. Renegotiation takes place if trade is efficient but the private contractor is not willing to complete the project because the ex-ante contracted trade price is too low. In such a case the welfare-optimizing procurement agency will (and should) offer renegotiation which leads to a higher trade price. This is a rational justification of soft budget constraints.

In Hart and Moore (1988) both actors are self-interested; when they decide on trade, the seller wants to maximize $p - c$, the buyer's objective is maximizing $v - p$, whereas in our model the public buyer wants to maximize welfare. The different objective function of the buyer induces not only a welfare-optimal result, but also leads to a significant difference in the renegotiations. While in Hart-Moore's setting the buyer sometimes refuses trade under the initial prices, this cannot occur if a welfare-maximizing agency is concerned. Hence, the ex-ante contracted trade price is never reduced in equilibrium.

In our setting the optimal contract inevitably leads to renegotiation in some states of nature if there is ex-ante uncertainty about the subsequent desirability of the project completion. It is interesting to note that this result is independent of the very characteristics of the underlying probability distributions. If there is no uncertainty, the result changes drastically. In this case the optimal contract requires that the supplier becomes the residual claimant to his cost savings in all states of nature. Hence, renegotiation never occurs. This dichotomy is in accordance with empirical evidence where the upward-renegotiation of an ex-ante fixed trade price is observed only if uncertain projects requiring innovation are considered.

Our results hold strictly for the case of negligible shadow costs of public funds. Eliminating this assumption, the outcome is preserved if the government can credibly commit not to consider the shadow costs of the seller's ex-post profits after the initial contract has been signed. If such a commitment is not feasible, the first-best result breaks down for both-sided investments. In contrast to common beliefs this inefficiency result is the consequence of too tough government behavior: if the procurement agency would not attempt to reduce the firm's ex-post profits, efficient investments could be attained.

The outcome of this paper furthermore supports the common belief that, in order to give firms innovation incentives, potential rents must accrue at the production stage. This holds even if the government from a welfare point of view is interested in extracting the contractor's expected profit. In the words of Rogerson, a 'prize' has to be paid to the firm in order to enhance innovative activity.

Appendix 1

In this appendix we consider a welfare function which reflects the costs of raising public funds. As a benchmark, let us derive the first best. First, the ex-post efficient decisions are

$$q^* = 1 \Longleftrightarrow \quad v_i \geq c_j(1+\lambda), \tag{A.1}$$

$$q^* = 0 \Longleftrightarrow \quad v_i < c_j(1+\lambda) \tag{A.2}$$

where λ refers to the shadow price of public funds. Second, the ex-ante efficient investments are given by the (unique) maximizers of the following program:

$$\text{maximize} \mathcal{W} = \sum_i \sum_{\substack{j \\ v_i \geq c_j(1+\lambda)}} \pi_i(a)\rho_j(e)[v_i - c_j(1+\lambda)] - (1+\lambda)(\psi(e) + \mu(a)). \tag{A.3}$$

Accordingly, the necessary and sufficient conditions for ex-ante efficient investments of the parties are implicitly determined by

$$\mathcal{W}_e(e^*, a^*) = 0 \Leftrightarrow \sum_i \sum_{\substack{j \\ v_i \geq c_j(1+\lambda)}} \pi_i(a^*)\rho_j'(e^*)(v_i - c_j(1+\lambda)) = (1+\lambda)\psi_e(e^*) \tag{A.4}$$

and

$$\mathcal{W}_a(e^*, a^*) = 0 \Leftrightarrow \sum_i \sum_{\substack{j \\ v_i \geq c_j(1+\lambda)}} \pi_i'(a^*)\rho_j(e^*)(v_i - c_j(1+\lambda)) = (1+\lambda)\mu_a(a^*). \tag{A.5}$$

If the government can credibly commit to neglect the shadow costs of the firm's ex-post profits, it will try to extract the seller's profits via the ex-ante choice of the no-trade price p_0. Under this commitment, after date 0 it will behave as in the first-best benchmark, that is its investment and renegotiation behavior is influenced only by the shadow costs of production and specific investments. Note that the ex-ante optimal contract under commitment inducing first-best investment decisions is qualitatively identical to that in the case of vanishing shadow costs. The optimal contracted price differential, of course, will be lower since the marginal benefit of production is decreased relative to the case of negligible shadow costs of public funds.

Under non-commitment, the government agency ex post agrees to trade if and only if

$$v_i \geq c_j + \lambda(p_1^T - p_0). \tag{A.6}$$

Beside the usual case of an upward renegotiation, under particular circumstances it is now possible that a downward renegotiation occurs. Suppose trade is efficient but (A.6) does not hold under the initial trade price (which implies that $(p_1 - p_0) > c$, that is the seller agrees to trade under the initial prices). Employing the Hart-Moore renegotiation game, in this case the seller holds the whole bargaining power in renegotiations and reduces the trade price so as to hold the procurement agency indifferent between trade and no trade. Accordingly, the ex-post realized trade price becomes

$$p_1^T = \begin{cases} p_1 & \text{if} \quad (v_i - c_j)/\lambda \geq p_1 - p_0 \geq c_j \\ p_0 + c & \text{if} \quad p_1 - p_0 < c_j \leq (v_i - c_j)/\lambda \\ p_0 + (v_i - c_j)/\lambda & \text{if} \quad p_1 - p_0 > (v_i - c_j)/\lambda \geq c_j. \end{cases} \tag{A.7}$$

Given any ex-ante contracted price tuple and inserting the subgame-perfect continuation of the game, at date 1/2 the objective function of the agency is

$$\text{maximize}_a\ \mathcal{G} = \sum_i \sum_{\substack{j \\ v_i \geq c_j(1+\lambda)}} \pi_i(a)\rho_j(e) max\{v_i - c_j - \lambda max\{p_1 - p_0, c\}, 0\} - \lambda p_0 - \psi(e) - \mu(a). \tag{A.8}$$

Choosing $p_1 - p_0 \leq \underline{c}$ yields efficient investments of the government agency in the subgame-perfect equilibrium of the game. Moreover, since a^N is decreasing in $(p_1 - p_0)$, increasing the initially contracted price difference above $\underline{c}$ induces underinvestment of the government agency [24]. Since the firm will never invest if $p_1 - p_0 \leq \underline{c}$ has been contracted, we observe that both-sided efficient investments are unfeasible under non-commitment.

Now, we examine whether one-sided efficient investments of the supplier can be attained. In this case, the firm's profit function at date 1/2 is

$$\text{maximize}_e\ \Pi = \sum_i \sum_{\substack{j \\ v_i \geq c_j(1+\lambda)}} \pi_i \rho_j(e) max\{min\{p_1 - p_0 - c_j, \frac{v_i - c_j(1+\lambda)}{\lambda}\}, 0\} + p_0 - \psi(e). \tag{A.9}$$

Let us evaluate whether there are initial prices which support first-best investments. First, consider $p_1 - p_0 \leq \underline{c}$. Under this ex-ante price differential, the seller does not invest into relationship-specific assets. Now, assume $(p_1 - p_0) \geq (\bar{v} - \underline{c})/\lambda$. Under

[24] To be more precise, this statement does not hold if $\underline{c} < \underline{v}$. In this case, efficient investments of the government require the weaker condition $p_1 - p_0 \leq \underline{v}$. In a continuous version of the model, of course, this remark has no relevance.

this specification, there is downward renegotiation of ex-ante contracted prices in every state where trade is efficient and the firm's objective becomes

$$\text{maximize}_e \ \Pi = \sum_i \sum_{\substack{j \\ v_i \geq c_j(1+\lambda)}} \pi_i(a)\rho_j(e)\frac{v_i - c_j(1+\lambda)}{\lambda} + p_0 - \psi(e). \qquad \text{(A.10)}$$

Comparing the efficiency condition (A.4) and the first-order condition of program (A.10), one immediately arrives at an overinvestment result. Since $de^N/d(p_1-p_0) \geq 0$ due to the MLRP, applying the mean-value theorem we can conclude that one-sided efficient investments of the firm can be guaranteed for any possible λ by the an ex-ante contract in the interval $\underline{c} < (p_1 - p_0)^* < (\bar{v} - \underline{c})/\lambda$. Interestingly, compared to the Hart-Moore result derived for a self-interested buyer, two different features arise: first, it is not valid any longer that there is downward renegotiation in *every* state of the world under the optimal contract; second, even if trade is realized with certainty (*i.e.*$\underline{v} \geq \bar{c}$), the ex-ante contract must be chosen such that renegotiation occurs in some states of the world. The intuition for both results lies in the fact that the firm under estimates the true social production (and investment) costs; accordingly, making it the residual claimant in all states of the world would induce overinvestment.

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