Incomplete Contracting and Target–Cost Pricing

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Abstract

Target-cost pricing has been a widely applied formula in defence contracting. If this type of pricing arrangement is chosen, the seller's ex-post profit consists of a fixed payment plus some share of the cost overrun, that is the difference between an ex–ante agreed estimation of the production costs and the actual production costs. In an incomplete–contract setting, where relationship–specific investments have to be made prior to the production stage, the cost-reimbursement properties of target-cost pricing work against a first best. However, since costs are verifiable, the ex–ante contract allows to condition the initial contract on costs, that is, to stipulate a separate trade price for each cost observation, plus a special price for the no–trade case. (If costs are non–verifiable, it is only possible to fix one price for trade and one price for non–trade.) This increase in the number of instruments available to the agents works in favour of a first best. The paper shows that the positive properties of target-cost pricing outweigh the negative ones: it is possible to find prices which induce the agents to invest efficiently into relationship-specific investments, thus avoiding Williamson's hold-up problem. This result is particularly important because fixed-price contracts a la Hart–Moore (1988) fail to achieve the first best if they are applied in the same environment in which target-cost prices succeed in attaining the first best. Since any contract, which implies full cost-reimbursement, also fails to achieve the first best, this paper shows that the first best requires just that middle-of-the-road approach which is offered by target-cost pricing.

1 Introduction

1.1 The Hold-up Problem in Government Procurement

The most interesting cases of national-defence procurement refer to advanced technology goods: prior to production particular R&D investments are required to develop just that good which best fits the government's demand. The R&D investments are relationship-specific. If the seller has invested in the development of a particular combat aircraft, and eventually the government does not buy this aircraft, the special technological innovations of the seller are assumed to be worthless. The same holds for investments of the government which improve the quality of the project, for instance the development of special anti-radar screens for combat aircraft. As is well known, this is Williamson's (1985) hold-up setting. During the initial R&D stage the relationship between the government and the private seller is governed by an incomplete contract: the amount of specific investments is non-verifiable before a court and so are the benefits of the project. Hence, ex-ante only a very rough contract can be written. Since the division of the net surplus from procurement cannot be fixed ex-ante, the parties cannot be prevented from renegotiating the contract when the benefit of the project finally becomes clear. However, at this date the costs of the relationship-specific investments are sunk and do not influence the final division of the net surplus. Anticipating this, both seller and buyer will under-invest in relationship-specific assets.

In a formal analysis, Hart–Moore (1988) corroborated this general under-investment result for the case of a private seller and a private buyer.[1] It has been shown[2] that one of the main reasons for their impossibility result is the assumption of at-will contracts: 'trade occurs if and only if the seller is willing to supply the good and the buyer is willing to take delivery of it; in stylized terms one can imagine that the buyer and the seller each has a switch which can be on or off, with trade occurring only if both switches are on.' (Hart–Moore, 1988, 758). For public procurement the assumption of at-will contracting seems quite adequate. There have been many examples where the government had to cancel procurement because of budgetary reasons (and where the seller was compensated for cancellation). Similarly, there are examples, where the seller cancelled delivery and the government did not sue him for the one-sided breach of the contract (because it did not want to drive the seller into bankruptcy for fear of loss of votes, etc).

The Hart–Moore impossibility result has been derived for a profit-maximising seller and a profit-maximising buyer. However, in the case of public procurement, we can impute to the buyer the objective of welfare and only the seller will be further interested in profits. This should make it easier to achieve efficiency. In fact, Bös–Lülfesmann (1996) show that efficient R&D investments of both government and private seller can be achieved by fixed-price procurement contracts of the at-will type.[3] This result, however, crucially de-

[1] Hart–Moore (1988), proposition 4.

[2] Chung (1991), Aghion–Dewatripont–Rey (1994), Nöldeke–Schmidt (1995)

[3] Bös–Lülfesmann (1995) extend the analysis to the case of design change. This extension is of no relevance for the present paper.

pends on the way the government procurement agency implements the welfare objective. The first best is achieved only if the government ignores the shadow costs of raising the public funds which are necessary to pay for the project or, equivalently, if the government credibly commits not to consider these shadow costs when it comes to the renegotiation of the contract. If the shadow costs of public funds play a role in the renegotiations, once again it is impossible to achieve efficient R&D investments of both seller and buyer (Bös–Lülfesmann, 1996, appendix).

1.2 Can Target-Cost Pricing Solve the Hold-up Problem?

In the present paper we maintain the assumption of at-will contracts and assume that the government considers the shadow costs of public funds when it renegotiates the contract. Hence, by fixed-price contracts efficient R&D cannot be achieved. Therefore, we replace the fixed-price contract by a target-cost contract. Target-cost pricing has been a widely applied formula in defence contracting (see, for instance, Cummins (1977), Hartley (1969), Samuelson (1983) and Sandler–Hartley (1995)). If this type of pricing arrangement is chosen, the seller's ex-post profit is defined as:

$$Pr = ty + s(y - c), \tag{1}$$

where Pr is the profit, y is an ex-ante agreed estimation of the production costs, c are the actual production costs, and t and s are parameters, which typically are defined on the $(0, 1)$–interval. The seller's profit, accordingly, consists of a fixed proportion of the estimated costs ty minus some share s of the cost overrun $(c - y)$. We assume that the cost estimate y as well as the parameter t have been determined by bilateral negotiations between buyer and seller which took place before the contract was signed.[4] The sharing parameter s, however, in our paper is not open to bilateral negotiations between the contract partners: there is rather one and only one value of s which prior to the contracting has been set by some superior government authority in such a way that it guarantees the first best.[5] In any case, both seller and buyer know y, t and s when signing the contract. The actual costs c, however, are not precisely known at that date.

A priori the consideration of target-cost pricing instead of a fixed price should make things worse, not better: we know that the hold-up problem is worst if the seller is fully reimbursed for the production costs. In that case the seller has no incentive to engage in expenses for R&D which may reduce the final production costs, hence he will not invest at all. Target-cost pricing implies at least a partial reimbursement and this should make it more difficult to achieve efficient investments – at least we would expect the seller's moral hazard to lead to reduced R&D investments compared with a fixed-price contract.

[4] In our model y is given at the moment of contracting and does not change during the further stages of the game, regardless of whether it really is the expected value of c or some other outcome from negotiations between the contract partners. Since neither t nor y play any major role in our approach, we do not explicitly model the bargaining procedure.

[5] See equation (25) below.

However, there is one further major difference between target-cost and fixed-price contracts. This difference refers to the verifiability assumptions. The application of target-cost pricing requires that the production costs are verifiable before a court, although they will be assumed to be stochastic at the moment of contracting. This is a deviation from the usual literature on the hold-up problem in incomplete contracting, which assumes non-verifiable production costs. Our justification for this special assumption is two-fold:

- target-cost pricing is a formula which is widely applied in practice. If it were really impossible to verify costs before a court, this formula could not be applied in practice.
- non-verifiability of the relationship-specific investments seems to be an unavoidable assumption because they are efforts of the individuals and efforts are non-verifiable. Similarly, the assumption of non-verifiability of the benefits of the public project is unavoidable because benefits are subjective in nature. Production costs, however, are objective in nature and, in spite of many possible accounting tricks, much more accessible to verification before a court.

Starting from the assumption of non-verifiable costs, fixed-price contracts of the Hart–Moore (1988) type can only be conditioned on the ex-post verifiable events 'trade' or 'no trade' and on the ex-post verifiable payment of the government. Hence, only two prices can be stipulated in the initial contract: a price p_1 if there is trade, and a price p_0 if there is no trade. In target-cost contracts, however, the verifiability of costs makes it possible to condition the initial contract on costs, that is, to stipulate a separate trade price for each cost observation (plus the price p_0 for the no-trade case).

Whether target-cost contracts do better than fixed-price contracts, therefore, depends on two countervailing effects:

- The partial cost reimbursement of target-cost pricing will induce the seller to underinvest in R&D; this disincentive is not given by a fixed- price contract;
- the conditioning of prices on costs implies that there are many more instruments which can be used to give investment incentives to the seller.

It is not a priori clear which of these two effects is more important. As we shall see, the positive properties of target-cost pricing prevail. They make it possible to achieve the first best where both fixed-price constracts and full cost reimbursement fail to do so. Hence, it is the main message of this paper that in incomplete contracting optimality may sometimes be achieved by arrangements which combine several formulas which taken for themselves would fail to achieve efficiency.[6]

[6] For the sale of one unit of a project, rewrite the target-cost formula as
$p = Pr + c = a_o + a_1 c$,
where $a_o = (t+s)y$ is the fixed-price part and $a_1 = (1-s)c$ is the cost-reimbursement part. This, in fact, is the way we shall apply the target-cost approach in the present paper, see equation (2) below.

The paper is organised as follows. In section 2 we present the stages of the procurement game. Since this is a multistage game, it has to be solved by backward induction. Accordingly, we start at the end of the game and in section 3 deal with the efficiency of the trade decision *(ex-post efficiency)*. Only then do we step back and in section 4 concentrate on the efficiency of the R&D-stage *(ex-ante efficiency)*. Finally, still in section 4, we consider the initial contract: do there exist initial prices which induce both ex-ante and ex-post efficiency? After answering this question, in section 5 we investigate the properties of these prices, in particular of the implied sharing parameter s. A short conclusion follows.

2 The Model

2.1 The Stages of the Game

We assume that the best candidate for the supply of some project has been sorted out by the government and that now the private seller and the government procurement agency are going to write a contract on the sale (purchase) of the project. This contract governs the complete future relationship between buyer and seller. This implies that one contract is written which refers to both development and construction. The objective of this paper is to show that it is just this long-term contract which can achieve the first best.[7]

At all stages of the game both players have symmetric information:[8] both players observe both R&D investments as soon as they are made; both players share the same priors with respect to the expected benefit and costs of the project; and at the same time they learn to know the actual benefit and costs. Both actors are risk-neutral: if they are only incompletely informed, they maximise expected welfare and profit, respectively. Note that this risk neutrality is combined with concave objective functions whose functional structure exhibits a particular form of risk aversion which can be responsible for risk sharing between the agents. The risk, which the agents may decide to share, is due to the fact that they have to sign a contract and to invest in R&D before knowing the actual benefit and costs of the project. To make life simple, in this paper we assume that there are only two possible realisations of benefit, $v \in \{\overline{v}, \underline{v}\}$, and similarly for costs, $c \in \{\overline{c}, \underline{c}\}$. We assume that the government finds it reasonable to share a cost overrun in both the low- and the high-cost case. Hence, it is not necessary for the government to impose a maximum-price liability above which it would not be willing to pay.[9]

The game structure is illustrated by Figure 1.

[7]In practice ministries of defence often sign two contracts: one for development and one for construction. This is an inefficient procedure unless the government buyer cares for pure welfare, even excluding shadow costs of public funds.

[8]It is the state of the art to assume symmetric information of the actors. Extending this type of model to asymmetric information is a top priority on the research agenda.

[9]In practice procurement agencies typically stipulate such a maximum-price liability in the contract to avoid sharing of ludicrously high cost overruns.

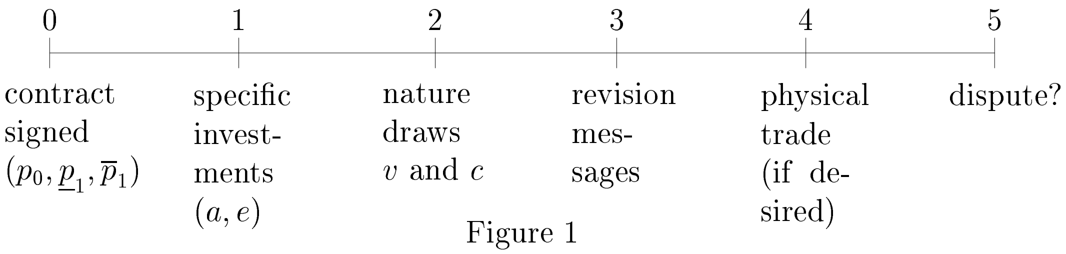

Figure 1

At *date 0* the agents write an incomplete contract. It is incomplete because the specific investments a and e, and the benefit of the project, v, cannot be verified before a court. Therefore, the only possible contract stipulates the following three prices:[10]

- a no-trade price p_0 for a quantity $q = 0$.
- a trade price $\overline{p}_1$ if the quantity $q = 1$ has been produced at costs $\overline{c}$,
- a trade price $\underline{p}_1$ if the quantity $q = 1$ has been produced at costs $\underline{c}$.

The trade prices p_1 are linked by the target-cost formula. Since we deal with the sale of one unit of a project, in case of trade the seller's revenue is equal to the trade price of the project, that is:

$$p_1 = Pr + c = (t + s)y + (1 - s)c. \tag{2}$$

Hence, for two cost observations $\overline{c}$ and $\underline{c}$ we have two trade prices $\overline{p}_1$ and $\underline{p}_1$, given the same values of t, s and y. Note that the link between the trade prices according to (2) implies $\overline{p}_1 - \underline{p}_1 = (1 - s)(\overline{c} - \underline{c})$.

The no-trade price can be interpreted as a reward for the seller's relationship-specific efforts.[11] The trade prices pay for both the costs of the specific investments and for the costs of the subsequent completion of the project. Hence, one can think of p_0 as the reward for innovation and $p \equiv p_1 - p_0$ as the reward for production.

At *date 1*, both agency and seller engage in relationship-specific investments. The agency invests an amount of a at costs $\mu(a)$; the seller invests e at costs $\psi(e)$. Both investment-cost functions are convex in the arguments. The investment (effort) levels are commonly observed by the two parties, but are not verifiable before a court.

At *date 2* nature draws the actual realization of benefit and costs. This draw of nature depends on the relationship-specific investments: higher investments of the government agency increase the probability of nature's drawing the high benefit $\overline{v}$,

$$\pi(a) = \text{prob}\{v = \overline{v} \mid a\}; \qquad \pi' > 0,\, \pi'' \leq 0. \tag{3}$$

Similarly, higher investments of the private seller increase the probability of nature's drawing the low costs $\underline{c}$,

$$\rho(e) = \text{prob}\{c = \underline{c} \mid e\}; \qquad \rho' > 0;\, \rho'' \leq 0. \tag{4}$$

[10] We deal with procurement of one unit of an indivisible good, the project. Hence $q = 0$ and $q = 1$ are the only possibilities.

[11] Note that p_0 can be negative.

At *date 3* the contract can be renegotiated. For this purpose, let us apply Hart–Moore's renegotiation game.[12] At date 3, therefore, the agents can submit messages to each other which contain new price offers. The offers are non-verifiable in the sense that each party can deny the reception. Hence, if one party receives a message, it can freely choose to reveal it to the court at date 5 in the case of a dispute on payments. In this setting the whole bargaining power in the renegotiation is (endogenously) assigned to that party which agrees to efficient trade under the initial prices.

Finally, at *date 4*, the good is produced and traded (if agreed upon) and the corresponding payments are provided. The game ends unless there are disputes on delivery and on payments, which would be decided at *date 5*. (In the subgame-perfect equilibrium no such disputes occur.)

2.2 Objectives and First-Best Benchmark

The private seller is a profit maximiser whose objective is:

$$U^S = \begin{cases} E(p^T - c \mid q = 1) + p_0 - \psi(e) & \text{at dates } 0, 1, \\ q(p^T - c) + p_0 & \text{at date } 3, \end{cases} \tag{5}$$

where the expectation operator E refers to the states of the world, that is to nature's draw of benefit and costs, conditional on the parties' specific investments. $p^T \equiv p_1^T - p_0$ is the realized price difference, that is either the ex-ante contracted price difference $p_1 - p_0$ or the modified price difference resulting from ex-post renegotiations. Considering the expectation operator implies that the application of the trade rule (that is, the subgame-perfect continuation of the game) is internalised. Note that at date 3 the investment costs are sunk and $\psi(e)$ is no longer included in the seller's objective function. The seller is willing to participate in the procurement game unless his expected profit at the moment of contracting is negative.

The government procurement agency, on the other hand, is a welfare maximiser that explicitly considers the shadow costs of raising public funds $\lambda \in (0, 1)$.[13] Each dollar paid by the government costs $(1+\lambda)$ dollars because it is financed from distortionary taxation. In a welfare context, the payment itself is considered as a welfare-neutral transfer; however, the shadow costs of funding the final payment, λp_0 or λp_1^T, have always to be taken into account by the government. Accordingly, the procurement agency's objective function

[12] More precisely (Nöldeke–Schmidt, 1995), we should speak of an ϵ-subgame-perfect equilibrium: to guarantee uniqueness in the Hart–Moore renegotiation game, we need the additional assumption that messages between the agents are infinitesimally costly.

[13] In a *theoretical* setting Laffont–Tirole's (1993) use of λ in their welfare considerations has become particularly well-known. Typical *empirical* estimations lead to $0 < \lambda < 1$, where values between 0 and 0.5 can be found more often, at least in developed countries; see, in particular, Ballard–Shoven–Whalley (1985), 136. For a brief overview of various empirical estimates see Jones–Tandon–Vogelsang (1990), 28-30.

equals:

$$U^B = \begin{cases} E(v - c - \lambda p^T \mid q = 1) - \lambda p_0 - \psi(e) - (1+\lambda)\mu(a) & \text{at dates } 0, 1, \\ q(v - c - \lambda p^T) - \lambda p_0 & \text{at date } 3. \end{cases} \tag{6}$$

The investment costs are no longer relevant when the government maximises U^B at date 3.

For later reference, we derive a *first-best benchmark*. For this purpose we consider a welfare-maximising government which does the whole job on its own, that is, it does not buy the project from a profit-maximising seller, but produces it itself. Therefore it has to use distortionary taxation to finance all the various costs which emerge in the realisation of the project: $\mu(a), \psi(e)$, and c. Hence, any of these costs, if they are spent, have to be multiplied by $(1 + \lambda)$.[14]

The first-best benchmark 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. It requires trade to take place if and only if this increases welfare, that is:

$$q^* = 1 \Leftrightarrow v \geq c(1+\lambda), \tag{7}$$
$$q^* = 0 \Leftrightarrow v < c(1+\lambda), \tag{8}$$

where v and c are the actual realisations of benefit and costs, respectively. Given this definition of ex-post efficiency, it should be clear to the reader that the analysis of this paper can be greatly simplified by assuming that:

$$\overline{v} > \overline{c}(1+\lambda) > \underline{v} > \underline{c}(1+\lambda). \tag{9}$$

This assumption constitutes a relation between benefit and 'gross costs' of the project, with a characteristic overlap as illustrated in Figure 2.

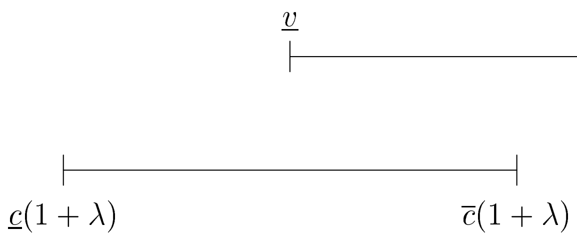

Figure 2

Hence trade is always efficient unless low benefits of the project and high production costs occur simultaneously.

Ex-ante efficiency refers to the optimal choice of the R&D investments a and e, that is, to the agents' decisions at date 1:

$$(a^*, e^*) \in \text{argmax}_{a,e} W = E(v - c(1+\lambda) \mid q = 1) - (1+\lambda)(\mu(a) - \psi(e)). \tag{10}$$

[14] In the government agency's objective function $\psi(e)$ is a welfare loss which is financed by a private seller and not by distortionary taxation. Hence $\psi(e)$ in equation (6) is *not* multiplied by $(1+\lambda)$.

a^* and e^* are used as a benchmark to be compared with the actual investments resulting from the two actors' Nash equilibrium at stage 1 of the game. We assume that there is a unique solution of the benchmark model.[15] This solution can be described by two first-order conditions which are necessary and sufficient for an interior solution $a^*, e^* > 0$.

Finally, let us define a *first-best result*: it is attained if in the subgame-perfect equilibrium the target-cost price differences $\overline{p}_1 - p_0$ and $\underline{p}_1 - p_0$, chosen at date 0, induce both ex-ante and ex-post efficiency. Note that by arbitrary choices of the absolute values of p_0 (or $\overline{p}_1$ and $\underline{p}_1$, respectively), any distribution of ex-ante utilities of the parties can be achieved; in particular, the ex-ante expected profits of the private seller can be reduced to zero.

Given our particular specification, the benchmark objective function equals:

$$\begin{aligned} W &= \pi(a)(1-\rho(e))[\overline{v} - \overline{c}(1+\lambda)] + \pi(a)\rho(e)[\overline{v} - \underline{c}(1+\lambda)] \\ &\quad +(1-\pi(a))\rho(e)[\underline{v} - \underline{c}(1+\lambda)] - (1+\lambda)[\mu(a) + \psi(e)]. \end{aligned} \tag{11}$$

Hence, we obtain the following two marginal conditions for efficient relationship-specific investments:

$$W_a = 0: \quad \pi'[\overline{v} - \overline{c}(1+\lambda) - \rho(\underline{v} - \overline{c}(1+\lambda))] = (1+\lambda)\mu', \tag{12}$$

$$W_e = 0: \quad \rho'[\underline{v} - \underline{c}(1+\lambda) - \pi(\underline{v} - \overline{c}(1+\lambda))] = (1+\lambda)\psi'. \tag{13}$$

3 Ex-post Efficiency

In this section we consider the agents' decision on trade at date 3. From the agents' objective functions (5) and (6) we recall that the seller wants to sell iff:

$$p^T \geq c, \tag{14}$$

and that the procurement agency wants to buy iff:

$$v - c \geq \lambda p^T. \tag{15}$$

In the above equations, v and c are the realized benefits and costs at date 3. If nature has drawn high costs, then the price difference p^T is either $\overline{p}_1 - p_0$ or some renegotiated $\overline{p}_1^T - p_0$. If nature has drawn low costs, the reasoning is analogous.

We first note that there will be no trade if $v < (1+\lambda)c$. This can be shown easily. Taking together equations (14) and (15) shows that trade requires $(v-c)/\lambda \geq p^T \geq c$. If $v < (1+\lambda)c$, this requirement cannot be met.

Let us next consider how the plans of the two agents match if $v \geq (1+\lambda)c$. Given the ex-ante contracted price difference $p \in \{\underline{p}, \overline{p}\}$, the following three cases can occur:

[15] Formally, the existence of an interior solution is ensured since expected welfare as defined in (10) is concave in both of its arguments and the Inada conditions are assumed to be fulfilled. The maximum is unique if one assumes $\mid W_{ii} \mid > \mid W_{ij} \mid, i, j \in \{a, e\}$.

(i) $p > (v - c)/\lambda \geq c$
At this high price difference, the buyer does not want to buy, whereas the seller of course wants to sell. In this situation, in the Hart–Moore renegotiation game the seller offers a lower price p_1^T which makes the buyer just indifferent between buying or not, that is, $p^T = (v - c)/\lambda$.[16] This is a downward renegotiation.

(ii) $(v - c)/\lambda \geq p \geq c$
At this price difference, both players are willing to trade at the initially contracted price difference. No renegotiation occurs.

(iii) $(v - c)/\lambda \geq c > p$
At this low price difference, the seller does not want to sell, whereas the buyer wants to buy. Hence, in the Hart–Moore renegotiation game, the seller offers a higher price p_1^T which makes the seller just indifferent between selling or not, that is, $p^T = c$. This is an upward renegotiation.

Hence, ex-post efficiency will always be achieved, if necessary by downward or upward renegotiation.

Before concluding this section, we should present some more details of the particular properties of the price difference p^T. For this purpose we distinguish three cases A,B,C, corresponding to those benefit-cost combinations which induce trade. We denote the final trade-price differences in these cases by p^A, p^B, and p^C (which are all special cases of p^T). The detailed presentation of all of these price differences is given in Table 1.

Table 1: Final Price Differences

	(i)	**(ii)**	**(iii)**
	downward renegotiation	no renegotiation	upward renegotiation
A: $\overline{v}, \overline{c}$	$p^A = (\overline{v} - \overline{c})/\lambda$	$p^A = \overline{p}_1 - p_0$	$p^A = \overline{c}$
B: $\overline{v}, \underline{c}$	$p^B = (\overline{v} - \underline{c})/\lambda$	$p^B = \underline{p}_1 - p_0$	$p^B = \underline{c}$
C: $\underline{v}, \underline{c}$	$p^C = (\underline{v} - \underline{c})/\lambda$	$p^C = \underline{p}_1 - p_0$	$p^C = \underline{c}$

In this Table, the target-cost formula has been integrated in the no-renegotiation case: contrary to a fixed-price contract without conditioning on costs, we have prices $\overline{p}_1$ and $\underline{p}_1$.[17]

4 Ex-ante Efficiency

We now examine the Nash equilibrium at date 1 where both the procurement agency and the private seller choose their R&D investments for given initial price differences $\underline{p}$ and $\overline{p}$,

[16] As usual in this sort of literature, we assume that the buyer will buy in such a situation of indifference.
[17] In the case of a fixed-price contract, in column (ii) we have $p^A = p^B = p^C = p_1 - p_0$. Columns (i) and (iii) are the same as in Table 1.

and for perfectly anticipated final price differences p^A, p^B and p^C.

The government procurement agency maximises the following objective function, where, to avoid messy notation, we have suppressed the explicit functional dependencies of $\pi(a), \mu(a), \rho(e)$ and $\psi(e)$:

$$U^B = \pi(1-\rho)(\overline{v}-\overline{c}-\lambda p^A)+\pi\rho(\overline{v}-\underline{c}-p^B)+(1-\lambda)\rho(\underline{v}-\underline{c}-\lambda p^C)-\lambda p_0-\psi-(1+\lambda)\mu. \quad (16)$$

Differentiation with respect to the agency's investments yields the following marginal conditions:

$$\pi'[\overline{v}-\overline{c}-\lambda p^A-\rho(\underline{v}-\overline{c})-\rho\lambda(-p^A+p^B-p^C)] = (1+\lambda)\mu'. \quad (17)$$

The private seller, on the other hand, maximises profit according to:

$$U^S = \pi(1-\rho)(p^A-\overline{c})-\pi\rho(p^B-\underline{c})+(1-\pi)\rho(p^C-\underline{c})+p_0-\psi(e) \quad (18)$$

and chooses his investment effort as results from the following marginal condition:

$$-\pi\rho'(p^A-\overline{c})-\pi\rho'(p^B-\underline{c})+(1-\pi)\rho'(p^C-\underline{c}) = \psi'. \quad (19)$$

We now have derived two first-order conditions which yield unique positive effort levels a^N and e^N.[18] These levels are not necessarily welfare-optimal. The welfare-optimal levels a^* and e^* result from the first-order conditions (12) and (13)! It is a priori clear that the seller's profit maximisation will not generally coincide with welfare maximisation. It is also clear that the procurement agency maximises a welfare function which deviates from the benchmark welfare function: the benchmark welfare does not refer to any prices, but the agency's welfare function does.

According to equations (17) and (19) the efforts a^N and e^N depend on the price differences p^A, p^B and p^C which are triggered by the initial price differences $\underline{p}$ and $\overline{p}$. Hence we can ask the following question: are there initial price differences which induce efforts a^N and e^N which are just equal to a^* and e^*, respectively?

To begin our search for these optimal price differences, let us first look at the *government agency's investments*. Equality of a^N and a^* requires the simultaneous validity of equations (12) and (17). Hence, for given $e = e^*$, we equate the terms in square brackets in (12) and (17) and obtain the following equation:

$$\overline{c} = p^A + \frac{\rho}{(1-\rho)}(p^B - p^C). \quad (20)$$

Are there price differences $\underline{p}$ and $\overline{p}$ which make this equation valid? Since the seller will only agree to trade if $p^A \geq \overline{c}$, the above equation can only be fulfilled by price differences:

$$p^A = \overline{c}, \quad p^B = p^C. \quad (21)$$

[18]For the assumptions which ensure this result, see footnote (15) above.

The requirement $p^A = \overline{c}$ can easily be met by setting $\overline{p} = \overline{p}_1 - p_0 = \overline{c}$ which excludes renegotiations in case A.

The requirement $p^B = p^C$ excludes the case of downward renegotiations, where p^B would depend on $\overline{v}$ and p^C on $\underline{v}$. (See column (i) in Table 1 above). Hence, there are two options for $\underline{p} = p^B = p^C$, namely:

- $(\underline{v} - \underline{c})/\lambda \geq \underline{p} > \underline{c}$

  which price difference does not trigger any renegotiation, case (ii) in Table 1 above, or alternatively:

- $\underline{p} < \underline{c}$

  which price difference induces upward renegotiation to $p^B = p^C = \underline{c}$, case (iii) in Table 1 above.

However, only the no-renegotiation case is applicable. The upward-renegotiation case is incompatible with the target-cost link between $\underline{p}_1$ and $\overline{p}_1$. This can be shown easily: substituting the target-cost pricing formula (2), the requirement $\overline{p}_1 - p_0 = \overline{c}$ can be rewritten as $p_0 = (t+s)y - s\overline{c}$. The requirement $\underline{p}_1 - p_0 < \underline{c}$ implies $(t+s)y - s\underline{c} < p_0$. Taken together we obtain the requirement $(t+s)y - s\underline{c} < p_0 = (t+s)y - s\overline{c}$ which cannot hold.

We conclude that $a^N = a^*$ can be achieved by adequately chosen price differences $\underline{p}$ and $\overline{p}$ in such a way that there will never be renegotiation.

Let us now turn to the *seller's investments*. Equality of e^N and e^* requires the simultaneous validity of equations (13) and (19). Combining these equations we obtain

$$\underline{v}(1-\pi) = (1+\lambda)[\pi(p^B - p^A) + (1-\pi)p^C]. \tag{22}$$

An optimal investment e^* will only be attained if equation (22) holds for $a^N = a^*$. This, however, can only hold if $p^A = \overline{c}$ and $p^B = p^C$. Substituting into (22), we obtain:

$$\underline{p} = \frac{1-\pi(a^*)}{1+\lambda}\underline{v} + \pi(a^*)\overline{c} \tag{23}$$

Hence, there is a unique solution of $\underline{p}$ and $\overline{p}(=\overline{c})$ which induces efficient investments a^* and e^*.[19]

Unfortunately, this unique solution holds only for particular realisations of the exogenous variables, in particular, it holds for low λ only. The reason is intuitive. Recall that $\underline{p}$ and $\overline{p}$ must be chosen in such a way that renegotiations never occur. Hence, efficiency requires $(\underline{v} - \underline{c})/\lambda \geq \underline{p} > \underline{c}$.[20] The right-hand-side inequality is always fulfilled given our

[19] Note that $\pi(a^*)$ is a constant value which is verifiable before a court: a^* can directly be calculated from the benchmark welfare optimum without any knowledge of the buyer's actual choice of restructuring effort.

[20] This is simply the condition of the no-renegotiation case (ii) treated in the section on ex-post efficiency.

assumptions (9) on the relation of benefits and costs. The left-hand-side inequality holds if λ is low enough since the lower λ the higher the utmost-left term. Note that it is a priori plausible that low λ's allow the attainment of the first best: the lower λ, the more similar are the procurement agency's objective function and the benchmark welfare function; if λ approaches zero, they converge to each other.

Let us formulate this result as a proposition:

Proposition 1:

There exists a λ° such that for $\lambda \leq \lambda^\circ$ the first best can be attained by target-cost pricing which sets:

$$\begin{aligned} \overline{p} &= \overline{c} \\ \underline{p} &= \frac{1-\pi(a^*)}{1+\lambda}\underline{v} + \pi(a^*)\overline{c} \end{aligned}$$

Renegotiation never occurs.

Proof:
Consider $LHS = (\underline{v} - \underline{c})/\lambda \geq \underline{p} = RHS$. We have

$$\begin{aligned} &\lim_{\lambda\to 0} LHS = \infty, \quad \lim_{\lambda\to 0} RHS = (1-\pi(a^*))\underline{v} + \pi(a^*)\overline{c}, \\ &\lim_{\lambda\to \infty} LHS = 0, \quad \lim_{\lambda\to \infty} RHS = \pi(a^*)\overline{c}. \end{aligned}$$

Since both LHS and RHS are continuous in λ, there exists a λ° such that for $\lambda > \lambda^\circ$ the first best cannot be achieved (not even by renegotiations), whereas for $\lambda \leq \lambda^\circ$ the first best can be achieved.[21]

It is important to note that for any $\lambda > 0$, even if it is very small, fixed-price contracts fail to achieve the first best. For a precise proof see Appendix 1 of this paper. Proposition 1 therefore signals a clear superiority of target-cost pricing over fixed-price contracts.

5 The Sharing Parameter s

There is one final question which we have skipped in the preceding section, that is the target-cost link between $\underline{p}$ and $\overline{p}$. This link requires:

$$(1-s) = \frac{\overline{p}-\underline{p}}{\overline{c}-\underline{c}}. \tag{24}$$

We substitute for the price differences $\underline{p}$ and $\overline{p}$ as presented in Proposition 1. Then we obtain:

$$s = \frac{1}{\overline{c}-\underline{c}}\left[\frac{1-\pi(a^*)}{1+\lambda}\underline{v} + \pi(a^*)\overline{c} - \underline{c}\right]. \tag{25}$$

[21] λ° can explicitly be determined by solving the efficiency condition $(\underline{v}-\underline{c})/\lambda = [(1-\pi)/(1+\lambda)] + \pi\overline{c}$. However, this leads to a quadratic equation in λ whose solution of λ escapes economic interpretation.

The link between the optimal price differences, therefore, requires a unique sharing parameter whose value depends on the exogenous variables of the problem (and only on such exogenous variables).

In Appendix 2 of this paper we show that s according to (25) always lies in the interval $0 < s < 1$ and we also present a detailed comparative-static analysis whose results are as follows:

$$\partial s/\partial \underline{v} > 0; \partial s/\partial \overline{c} < 0; \partial s/\partial \underline{c} < 0; \partial s/\partial \pi(a^*) > 0; \partial s/\partial \lambda < 0. \tag{26}$$

How to interpret these results? The comparative-static analysis shows that under incomplete contracting the sharing parameter s is not chosen so as to share risks. By way of an example, if s were a risk-sharing parameter, we would expect $\partial s/\partial \lambda > 0$: the larger λ, the more weight is given to cost-overruns in the agency's objective function; [22] increasing λ increases the share of risk taken by the government; this would have to be balanced by shifting some of this risk to the firm, that is, by increasing s. However, as we saw in (26), we have $\partial s/\partial \lambda < 0$ which is just the opposite sign.

In our incomplete-contract setting with renegotiation the parameter s plays a totally different role. The optimal contract requires two separate trade prices $\underline{p}_1$ and $\overline{p}_1$. A priori, these prices are not connected. However, the target-cost formula requires a particular link between these prices, as shown in (24). Now recall the precise definitions of the trade prices:

$$p_1 = (t + s)y + (1 - s)c. \tag{27}$$

It is immediately clear that the term $(t+s)y$ cancels if $\underline{p}_1$ is subtracted from $\overline{p}_1$. This term always shifts both prices in the same way and cannot be adjusted in order to link two arbitrarily chosen prices $\underline{p}_1$ and $\overline{p}_1$ in such a way that they correspond to the target-cost-pricing formula. Only adjustments of $(1 - s)$ can achieve that. Consider, for example, an increase in λ. Ceteris paribus this leads to a lower price difference $\underline{p}$. Hence, the spread of price differences $\overline{p} - \underline{p}$ is increased and, according to (24) this leads to an upward adjustment of $(1 - s)$, whence $\partial s/\partial \lambda < 0$. A similar reasoning holds for $\pi(a^*), \underline{v}$ and $\overline{c}$. [23]

6 Conclusion

When introducing the problem of this paper, we argued that there is a trade-off, where the cost-reimbursement properties of target-cost pricing work against a first best, and the increase in the number of instruments available to the agents works in favour of a first best. The paper has shown that the positive properties of target-cost pricing outweigh the negative ones: it is possible to find prices which induce the agents to invest efficiently into relationship-specific investments, thus avoiding Williamson's hold-up problem.

[22] Recall that in the welfare optimum we have no renegotiation, case (ii) of Table 1. Hence, in the objective function, say (16), we have terms $\lambda p^A, \lambda p^B, \lambda p^C$, which the target-cost formula directly links to the cost-overrun terms $(1 - s)(y - \underline{c})$ and $(1 - s)(y - \overline{c})$.

[23] For $\underline{c}$ the necessary adjustment follows directly from changing the denominator in (24) or in (25), respectively.

The result is particularly important because fixed-price contracts a la Hart–Moore (1988) fail to achieve the first best if they are applied in the same environment in which target-cost prices succeed in attaining the first best. Since any contract, which implies full cost-reimbursement, also fails to achieve the first best, this paper shows that the first best requires just that middle-of-the-road approach which is offered by target-cost pricing.

Appendix 1: The Impossibility to Reach the First Best by Fixed-Price Incomplete Contracting

Let us assume a contract-theoretic environment which is identical to that presented in the main part of this paper with the only exception that costs are assumed to be non-verifiable. Accordingly, the only possible contract stipulates a price p_0 for the no-trade case and (one and only one) price p_1 for the trade case.

The analysis of fixed-price contracts begins in just the same way as the analysis of target-cost contracts. We make the same assumptions on the stages of the game and, of course, the benchmark model is unchanged. Given the notation of our paper, all objective functions of seller and buyer are identical to those presented in the main part of the paper, hence there is no need to repeat them. Ex-post efficiency is achieved in the same way as in Section 3 of the paper; the only difference is $p^A = p^B = p^C = p_1 - p_0$ if there is no renegotiation. Hence the fixed-price analogue to Table 1 has only six prices for nine possible cases instead of seven prices for nine possible cases which characterise target-cost pricing.

The treatment of ex-ante efficiency also begins just as in section 4 of the paper. A fixed-price contract induces $a^N = a^*$ if

$$\bar{c} = p^A + \frac{\rho}{1+\rho}(p^B - p^C), \tag{A.1}$$

which is exactly the same formula as equation (20) for the target-cost contract. Once again, this formula requires $p^A = \bar{c}$ and $p^B = p^C$ which excludes the case of downward renegotiation.

However, the use of a fixed-price contract now makes it impossible to set a price difference $\bar{p} = \bar{c}$ and then choose some other price difference $\underline{p}$ for the low-cost cases. Hence, there are only two possibilities:

(i) Upward renegotiation in every case, leading to final price differences $p^A = \bar{c}$, $p^B = p^C = \underline{c}$ where $p_0 = 0$. Upward renegotiation occurs if $p_1 - p_0 \leq \underline{c}$. The government agency in this case chooses R&D investments according to the correct marginal condition. However, in case of $p_1 - p_0 \leq \underline{c}$, the seller will never invest in R&D. Hence, the first best cannot be achieved in this way. This is the result presented in Bös-Lülfesmann (1996), appendix.

(ii) No renegotiation. This case occurs if $p^A = p^B = p^C = \overline{c}$, which is compatible with the efficiency condition for the no-renegotiation case if is low.[24] However, $p^A = p^B = p^C = \overline{c}$ is a non-feasible option as can be shown by contradiction. For this purpose consider the seller's investment decision. Recall equation (22) of the main text which must hold if e^N is to be equal to e^*,

$$\underline{v}(1-\pi) = (1+\lambda)[\pi(p^B - p^A) + (1-\pi)p^C]. \tag{A.2}$$

Substituting for the price differences we obtain

$$\underline{v} = (1+\lambda)\overline{c} \tag{A.3}$$

which is a contradiction.

Summarising, the first best cannot be achieved by fixed-price contracts if the shadow costs of raising public funds are taken into account by the government agency.

Appendix 2: The Properties of the Sharing Parameter s

A.2.1 $s \in (0,1)$

Consider

$$s := \left[\frac{1-\pi}{1+\lambda}\underline{v} + \pi\overline{c} - \underline{c}\right]\frac{1}{\overline{c}-\underline{c}} \tag{A.4}$$

where we have abbreviated $\pi = \pi(a*)$ and have assumed that

$$\text{Ass. 1} \qquad \overline{c}(1+\lambda) > \underline{v} \tag{A.5}$$

$$\text{Ass. 2} \qquad \underline{v} > \underline{c}(1+\lambda) \tag{A.6}$$

We have $s > 0$, because

$$s = \left[\frac{1-\pi}{1+\lambda}\underline{v} + \pi\overline{c} - \underline{c}\right]\frac{1}{\overline{c}-\underline{c}} = \frac{1}{1+\lambda}[(1-\pi)\underline{v} + \pi\underbrace{(1+\lambda)\overline{c}}_{\substack{\text{Ass. 1}\\ \Rightarrow > \underline{v}}} - \underbrace{(1+\lambda)\underline{c}}_{\substack{\text{Ass. 2}\\ \Rightarrow < \underline{v}}}]\frac{1}{\overline{c}-\underline{c}} > 0. \tag{A.7}$$

We also have $s < 1$, since

$$\frac{\partial s}{\partial \pi} = \left[-\frac{1}{1+\lambda}\underline{v} + \overline{c}\right]\frac{1}{\overline{c}-\underline{c}} = \frac{1}{1+\lambda}[-\underline{v} + \underbrace{(1+\lambda)\overline{c}}_{\substack{\text{Ass. 1}\\ \Rightarrow > \underline{v}}}]\frac{1}{\overline{c}-\underline{c}} > 0 \tag{A.8}$$

$$\frac{\partial s}{\partial \lambda} < 0. \tag{A.9}$$

[24] $(v-c)/\lambda \geq p \geq c$ holds trivially for cases A and B. For case C, however, $(\underline{v}-\underline{c})/\lambda \geq \overline{c}$ holds for low λ only.

Hence for the maximum of $s(\pi, \lambda)$ for given values of $\underline{v}$, $\underline{c}$ and $\overline{c}$ we obtain

$$s_{max} = s(\pi_{max}, \lambda_{min}) = s(1, \frac{\underline{v} - \overline{c}}{\overline{c}}) = 1. \tag{A.10}$$

Similary, for the minimum we obtain

$$s_{min} = s(\pi_{min}, \lambda_{max}) = s(0, \frac{\underline{v} - \underline{c}}{\underline{c}}) = 0. \tag{A.11}$$

A.2.2 Comparative statics

$$\frac{\partial s}{\partial \underline{v}} = \frac{1-\pi}{1+\lambda}\frac{1}{\overline{c}-\underline{c}} > 0, \tag{A.12}$$

$$\begin{aligned}
\frac{\partial s}{\partial \pi} &= \frac{1}{\overline{c}-\underline{c}}\left[-\frac{1}{1+\lambda}\underline{v} + \overline{c}\right] \\
&= \frac{1}{\overline{c}-\underline{c}}\frac{1}{1+\lambda}[\underbrace{(1+\lambda)\overline{c}}_{\substack{\text{Ass. 1} \\ \Rightarrow > \underline{v}}} - \underline{v}] > 0,
\end{aligned} \tag{A.13}$$

$$\frac{\partial s}{\partial \lambda} < 0,$$

$$\begin{aligned}
\frac{\partial s}{\partial \overline{c}} &= \frac{\pi}{\overline{c}-\underline{c}} + \left[\frac{1-\pi}{1+\lambda}\underline{v} + \pi\overline{c} - \underline{c}\right]\frac{-1}{(\overline{c}-\underline{c})^2} \\
&= \frac{1}{(\overline{c}-\underline{c})^2}\left[\pi(\overline{c}-\underline{c}) - \frac{1-\pi}{1+\lambda}\underline{v} - \pi\overline{c} + \underline{c}\right] \\
&= \frac{1}{(\overline{c}-\underline{c})^2}\left[(1-\pi)\underline{c} - \frac{1-\pi}{1+\lambda}\underline{v}\right] \\
&= \frac{1-\pi}{(\overline{c}-\underline{c})^2}\frac{1}{1+\lambda}[\underbrace{(1+\lambda)\underline{c}}_{\substack{\text{Ass. 2} \\ \Rightarrow < \underline{v}}} - \underline{v}] < 0,
\end{aligned} \tag{A.14}$$

$$\begin{aligned}
\frac{\partial s}{\partial \underline{c}} &= -\frac{1}{\overline{c}-\underline{c}} + \left[\frac{1-\pi}{1+\lambda}\underline{v} + \pi\overline{c} - \underline{c}\right]\frac{1}{(\overline{c}-\underline{c})^2} \\
&= \frac{1}{(\overline{c}-\underline{c})^2}\left[-(\overline{c}-\underline{c}) + \frac{1-\pi}{1+\lambda}\underline{v} + \pi\overline{c} - \underline{c}\right] \\
&= \frac{1}{(\overline{c}-\underline{c})^2}\left[-(1-\pi)\overline{c} + \frac{1-\pi}{1+\lambda}\underline{v}\right] \\
&= \frac{1-\pi}{(\overline{c}-\underline{c})^2}\frac{1}{1+\lambda}[-\underbrace{(1+\lambda)\overline{c}}_{\substack{\text{Ass. 1} \\ \Rightarrow > \underline{v}}} + \underline{v}] < 0.
\end{aligned} \tag{A.15}$$

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