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Incomplete contracting and price regulation

by

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Abstract:
This paper deals with price regulation of a monopolistic distribution grid which sells a license to some retailer. The regulator aims at attaining efficient sale of the license and efficient relationship-specific investments of the agents. The first best can be attained by a sequential regulatory mechanism which gives the seller an option to grant the license but allows the buyer to make counteroffers. This sequential mechanism runs counter to the usual price-cap idea since possible upward but never downward renegotiation of the regulated prices is the vehicle to attain the first best.

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1 Introduction

The sustainability discussion has succeeded in destroying the myth of the 'natural-monopoly' properties of many public utilities. In cases of telecommunication, electricity, gas or water, it has become clear that only the distribution grid exhibits those economies of scale and scope which actually lead to a natural-monopoly position, whereas this does not hold for production and for retail sale. Consequently, public utilities may be disintegrated either vertically or horizontally, with possible privatization and market entry in those parts where no natural-monopoly properties prevail. There are many good examples for this kind of disintegration. Best known are the split-ups of the telecommunication industries in several countries. Another case in question is the British electricity industry which has been disintegrated in the course of privatization. In the case of British Gas the possibilities of disintegration have been intensively discussed quite recently.

If a distribution grid and the retailers are separated, then the government will regulate the grid because otherwise it would exploit its monopolistic position in order to maximize its profits. In this paper we deal with a price regulation which refers to the sale of a license from a distribution grid to some retailer. The license gives the licensee the right to procure electricity or gas or water from the grid and to use the grid for supplying these goods to private customers, be it firms or individuals.[1] We assume that identical licenses are sold to many licensees, whence there is price competition in the retail market and, therefore, the licensee need not be regulated. The grid, however, will make a monopoly profit unless it is regulated. The present paper deals with one of the many identical contracts between the grid and one particular retailer. For notational clarity in the following the terms 'buyer' and 'seller' will always be used with reference to the license: the distribution grid will always be called the seller (of the license), the retailer the buyer (namely, of the license). The sale of the license will synonymously be called 'trade.'

[1] Alternatively, the retailer may produce the electricity (or gas etc.) himself. In that case the license would only refer to the use of the grid for distribution.

The sale of a license is a long-term contract which grants the license for a legally predetermined time, say, five or ten years. At the moment of contracting, the benefits and costs which will result from trade are unknown. In this situation of uncertainty, both buyer and seller have the opportunity to invest in benefit-enhancing and in cost-reducing activities. These investments are relationship-specific. If the would-be buyer does not become the grid's licensee, then the technological innovations he has made for his future retailing are practically worthless. We assume that the same holds for the seller. This means that we restrict the analysis to specific investments of the grid which refer to this particular potential licensee, that is, they cannot be used if this potential buyer does not become the licensee and afterward some other firm buys the license. The latter assumption is not too far-fetched: it may well be that a potential licensee wants to implement a new technology which requires particular adjustments of the distribution grid. If the final licensee does not implement this technology, then the seller's adjustment investments are really worthless.

The specific investments are unverifiable efforts on which a contract cannot be conditioned. Moreover, at the moment of contracting it is impossible to describe in a verifiable way the benefit of the license which is subjective evaluation of the licensee. Therefore, ex-ante only an incomplete contract can be written, which cannot definitely fix the division of the net surplus from trade. This division will rather be determined at some later point of time, when the contractors have learned the respective realizations of benefit and costs. However, when this decision is made, the costs of the specific investments are sunk and do not influence the final division of surplus. Anticipating this hold-up, both seller and buyer will underinvest in relationship-specific assets (Williamson, 1985; Hart and Moore, 1988).

In this paper we show how a regulator is able to solve the hold-up problem. The basic features of the model are presented in section 2, in particular the special assumptions on the observability of the relationship-specific investments, and of benefit and costs of the license. The core of the paper, section 3, presents a sequential regulatory mechanism which gives the seller the option to grant the license but allows the buyer to make counteroffers. This mechanism works as if the contractors had written an option contract á la Nöldeke and Schmidt (1995), in spite of decisive differences in the models. The sequential mechanism attains the first best, if necessary by upward renegotiation of the prices which the regulator initially has set. Since this renegotiation runs counter to the usual price-cap idea, in section 4 we investigate whether the first best can also be attained by a regulated contract which does not allow the contractors to renegotiate the regulated prices. It will be shown that such a contract cannot guarantee the first best for all possible constellations of benefits and costs.

2 The model

2.1 The variables

Let us begin with defining *benefits and costs.* The benefits v characterize the licensee's valuation of the license. The actual realization of v is drawn by nature from a list $v_1 < ... < v_i < ... < v_I$, $I \geq 2$. c are the 'costs of the license', that is, the costs which the seller will have to incur to serve the licensee. These costs are also drawn by nature; the support of this draw is $c_1 < ... < c_j < ... < c_J$, $J \geq 2$.

Next, consider the *relationship-specific investments* of licensee and grid. The licensee invests an amount of a at costs $\mu(a)$; the grid invests e at costs $\psi(e)$. Both investment-cost functions are convex in the arguments and fulfill the Inada conditions. The investments a and e are scaled so that they both lie in $[0, 1]$.

Higher investments of the buyer increase the probability of nature drawing higher benefits. Following Hart and Moore (1988), we define this probability as follows:

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

where π^+ and π^- are probability distributions over $(v_1, ..., v_I)$ and π_i^+/π_i^- is increasing in *i (monotone likelihood ratio property).* Similarly, higher investments of the seller increase the probability of nature drawing low costs,

$$\sigma_j(e) = e\sigma_j^+ + (1 \Leftrightarrow e)\sigma_j^-. \tag{2}$$

σ^+ und σ^- are probability distributions over $(c_1, ..., c_J)$ and σ_j^+/σ_j^- is decreasing in j. Choosing a particular investment determines a linear combination of the probability distributions, for instance π^+, π^-. The monotone likelihood ratio property ensures first-order stochastic dominance. Hence, both agents prefer the better distribution (π^+, σ^+), which they can achieve better by higher investments. This implies that higher investments increase expected benefits, and decrease expected costs. From the definitions of the probability distributions $\pi(a)$ and $\sigma(e)$ it follows directly that the first derivatives are constant and that they sum up to zero:

$$\pi_i' = \pi_i^+ \Leftrightarrow \pi_i^-; \qquad \sigma_j' = \sigma_j^+ \Leftrightarrow \sigma_j^-; \qquad \textstyle\sum_{i=1}^I \pi_i' = \sum_{j=1}^J \sigma_j' = 0. \tag{3}$$

2.2 Information and verifiability assumptions

Let us begin with what seller and buyer observe. We assume a special case of 'partially-private information':

(i) each agent's investment is public information, that is, it can be observed by the other agent;[2]

(ii) the benefits of the license are private information of the buyer. In contrast, the costs are public information and observable by both seller and buyer.[3] These assumptions are plausible: benefit valuations include personal value judgements and therefore are very likely to be private information, whereas cost informations are based on nonsubjective facts and therefore easier to obtain.

Next, we have to state what the regulator observes. We assume that he cannot observe the investments a, e[4] and the actual realization of benefit v_i. However, he observes the cost realization c_j. These assumptions are plausible for the following reasons: the relationship-specific investments can be interpreted as a sort of 'effort' of the agents; buyer and seller know each other very well and hence observe the other's effort. The regulator, however, is more distant from seller and buyer, even if it is not exactly the 'arms-length approach' which had been postulated in the British history of regulation. Benefit, moreover, is subjectively determined, whence its non-observability is a natural assumption. On the other hand, at least since Laffont and Tirole's seminal 1986-paper 'Using cost observation to regulate firms' it has become a very usual assumption that cost realizations can be observed by a regulator. Since price regulation typically depends on costs, it intrinsically assumes that the regulator is able to observe the costs. This is particularly plausible if the grid is still publicly owned, whence the regulator as a government authority has direct access to the firm. However, as the UK practice illustrates, it also works in the case of private regulated grids.

Neither investments nor benefit can be specified in an objectively verifiable manner in the contract on the regulated sale of a license. Hence, the contract cannot be conditioned on a, e or particular values of v. – What, then, are observations on which the contract can be conditioned because they are verifiable? First, the events 'trade' or 'no trade,' that is, whether the license is granted or not. Second, the payments of the buyer, that is, a no-trade price p_0 and trade prices $\{p_{1j}\}$, one for each realization of costs. The many trade prices are due to the price regulation and allow the writing of an initial contract which deviates from the usual types of fixed-price contracts which stipulate only one trade price.

[2] This assumption is made because some of the best-known revelation mechanisms, when applied to the hold-up problem, fail to achieve the first best in the case of partially-private information; see subsection 2.3 below. Therefore, the sequential regulatory mechanism of this paper is most interesting in the case of publicly observable investments, although it works just the same if investments are private information.

[3] This assumption could be relaxed. Assume that seller and regulator observe the costs, but not the buyer. Then, by setting prices that depend on some non-strategic cost report made by the regulator, the regulator can effectively communicate its cost information to the licensee. This neutralizes any potential strategic cost reporting the grid might consider in order to achieve a more favorable price and this encourages more efficient investment by both parties.

[4] This setting is quite different from Besanko and Spulber (1992), whose regulator sets rates after observing the firm's investment.

Finally, as usual in models of this kind, all functions of the model are common knowledge, and so are the supports of benefits and costs.

2.3 Remark: relation to the literature

Rogerson (1992) investigated how the hold-up problem can be overcome by the application of various mechanism-design approaches. He was successful in solving two cases: complete private information (CPI) and no private information (NPI). In the CPI case each agent's investment choice and the realizations of benefit and cost are private information. Here, the first best can be attained by applying mechanisms developed by D'Aspremont and Gérard-Varet (1979) and by Cremer and Riordan (1985). In the NPI case, investments, benefits and costs are public information, that is, they are observed by the contractors, although not by the regulator (that is, the mechanism, which is the regulator, observes nothing). In this NPI case the Moore and Repullo (1988) mechanism is the adequate instrument to attain the first best, that is, both efficient trade and efficient investments.

The only informational setting which caused difficulties is the case of partially-private information (PPI), which in Rogerson's paper entails publicly observable investments and private information on benefit and costs. In this PPI case, the Cremer-Riordan mechanism implements the efficient outcome if only one party makes an investment choice. It fails if both parties invest. Intuitively, this failure can be explained as follows. The contract, in Rogerson, has to implement efficient trade given the announced 'types' of agents, that is, the benefits and costs. The correct revelation of types is elicited by 'subjectively discretionary' transfers, that is, transfers which do not depend on one's own announcement of type but only on the other agents' announcements, *given these others' investment choices.*[5] If the contractors are able to observe investment choices of the others', then the announcements respond if any other agent deviates from his Nash investment, hence a false type is announced and the first best is failed.

The present paper presents a case of partially-private information which, however, is not identical with Rogerson's: in his PPI approach both benefit and costs are private information. In the PPI approach of this paper only the benefit is private information; costs are public information. This makes the first best in a PPI case attainable by a sequential regulatory mechanism which does not require revelation of private information (benefit) and uses the public information (costs) to give the correct incentives for efficient investment. Since there is no revelation game with respect to benefit or costs, no direct connection between revelation and observable investments occurs. The contractors simply choose their Nash investments, anticipating the final decision which will be made on the granting

[5]For the precise definition see Rogerson (1992), p. 783.

of the license. Whether investments are observable or not, does not matter.

2.4 The stages of the game

There are three players in the game: the distribution grid as the seller of the license, a retailer as the buyer, and the regulatory agency. Buyer and seller are going to write a long-term contract which governs their complete future relationship. This contract, however, has to abide by particular prescriptions of the regulator. The time structure of the game is illustrated by Figure 1.

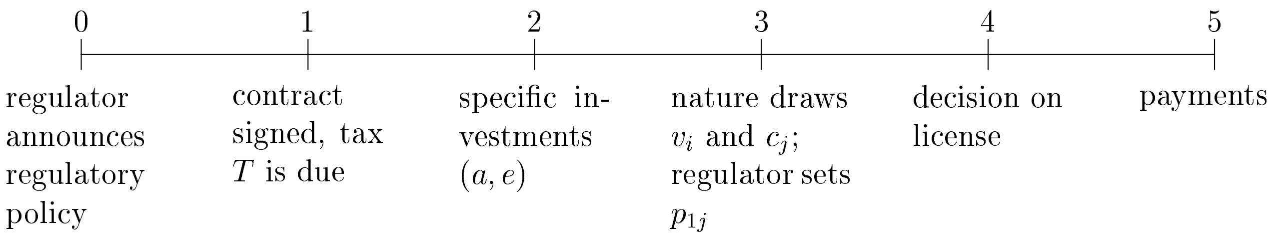

Fig. 1

At *date 0* the regulator announces a list of prices $\{p_{1j}\}$, requiring that the license is to be sold at a price p_{1j} if the costs are c_j.[6] This implies that prices are conditioned on costs, as is typical in many cases of public utility regulation. Cost-plus regulation is an extreme example, target-cost pricing is a mixture between conditioning on costs and fixed-price regulation (Bös, 1996). In its practical application, $RPI - X$ regulation also conditions on costs.[7] Although the theoretical concept allows for an exogenously given X, which does not necessarily condition on costs, in practice the factor X is chosen according to the firm's potential for price reduction: X should be high if productivity increases lead to considerable cost reductions which could be passed over from the firm to the customers. X should be low if productivity increases only slowly in some industry. In the British regulated utilities, for example, British Telecom always has had a high X, whereas British Gas has had a lower X.

Moreover, at date 0 the finance minister announces a lump-sum tax T which is due at the moment of contracting. (And the regulatory law forbids any further intervention of the minister.) This tax extracts all ex-ante rents of the game, that is, it is equal to the sum of the contractors' expected profits.

[6] We assume that the regulated prices refer to the whole term of validity of the contract (no regulatory revision) and that it is legally forbidden to give another license to the same licensee after expiration of the present contract.

[7] This is the British formula according to which an average price of some bundle of the regulated firm's products must not exceed the retail price index (RPI) minus a constant X which is set by the regulator. For details see Bös (1994), chapter 27.

At *date 1* grid and licensee write an incomplete contract. According to our verifiability assumptions, this contract can only be conditioned on the events 'trade' or 'no trade', and on costs, with one price for each cost realization. The quantity to be traded is either $q = 1$ or $q = 0$ since we deal with the 'trade' of one indivisible unit of a good, namely the license. Therefore, at date 1 grid and licensee write an incomplete contract with the following content:

$$q = 1 \quad \Leftrightarrow \quad \text{licensee pays } \; p_{1j} \text{ if } c = c_j, \tag{4}$$

$$q = 0 \quad \Leftrightarrow \quad \text{licensee pays } \; p_0. \tag{5}$$

Whereas the trade prices p_{1j} are chosen by the regulator, the no-trade price p_0 is chosen by the contractors. The contractors' choice of p_0 is anticipated by the regulator when he announces the prices $\{p_{1j}\}$. Hence, he can effectively determine the net prices $\{p_j\} := \{p_{1j} \Leftrightarrow p_0\}$. This is very important since in models of this type

– the net prices $\{p_j\}$ drive the efficiency results,

– whereas the no-trade price p_0 drives the distributional results, that is the sharing of ex-ante rents among the contractors.

In our paper, this sharing of ex-ante rents must be seen in connection with the finance minister's tax. The minister at date 1 levies a tax which extracts the sum of expected profits of seller and buyer. Now assume that no party will sign the contract unless its expected profit is non-negative (participation constraints, outside options). Therefore, the parties' only choice of p_0 equates to zero both seller's and buyer's expected profits.[8] This implies that buyer and seller typically will not share the total tax burden on a 50:50 basis. The tax burden of the grid will rather depend on the expected costs and the respective prices, whereas the tax burden of the licensee will depend on the expected benefits, costs, and the prices.

At *date 2*, both grid and licensee choose their relationship-specific investments which, in turn, determine nature's draw of benefit and costs of the license at *date 3*. At the same time the regulator observes the actual cost realization and sets the price p_{1j} according to his announcement. Note that this is one price only (not a set). The final decision on the granting of the license is made at *date 4*: the contractors decide within the framework of the prescribed regulatory scheme. In the main part of the paper this regulatory scheme will be a sequential mechanism, which allows renegotiation. Afterward, at *date 5* the li-

[8] Formally, the finance minister chooses a tax which is $T = U^B + U^S$, where the buyer's and the seller's before-tax utilities U^B, U^S are defined as in (13) and (14) below and where the net prices p_j are set to guarantee efficiency as explained in section 3 below. From the definitions of U^B and U^S it can be seen directly that the no-trade price p_0 is the instrument to shift monetary utility from one contractor to the other until the after-tax utilities of both contractors are equal to zero. The same holds for section 4, where the contractors' utilities are given by (18) and (19).

censee pays the grid. This is the end of the game unless there are disputes on the granting of the license and on payments. However, in the subgame-perfect equilibrium there will never be disputes before the court.

2.5 The objectives of the players

Both grid and licensee are risk-neutral profit maximizers. At dates 1 and 2, they maximize expected profits, perfectly anticipating the subgame-perfect continuation of the game. At date 4, they decide on trade on the basis of the actual benefit and costs of the license and of the corresponding price which has been set by the regulator. The relationship-specific investment costs are sunk at this date and do not enter the objective functions.

The regulator is a risk-neutral welfare maximizer. At date 0 he announces prices which maximize expected welfare, including the costs of relationship-specific investments. As we shall see, there exist regulatory policies which induce both efficient trade and efficient relationship-specific investments. Hence, at date 3 the regulator has no incentive to deviate from the regulatory policy which he chose at date 0.[9]

Detailed presentations of the players' objective functions will be presented in the following sections. The regulator's objective function is identical with the welfare function presented in the first-best benchmark.

2.6 First-best benchmark

The first best requires two notions of efficiency. First, *ex-post efficiency* refers to the decisions made at date 4. Recall that we deal with the sale of one unit of an indivisible good, the license. Hence, $q = 1$ and $q = 0$ denote 'trade' and 'no trade,' respectively. Efficiency requires that trade takes place if and only if it increases welfare, that is:

$$q^* = 1 \Leftrightarrow v \geq c, \tag{6}$$

$$q^* = 0 \Leftrightarrow v < c, \tag{7}$$

where v and c are the actual realizations of benefit and costs, respectively.

Second, *ex-ante efficiency* refers to the welfare-optimal choice of the relationship-specific investments a and e at date 2:

$$a^*, e^* \in \operatorname{argmax}_{a,e} \mathcal{W} = \sum_i \sum_{j \atop v_i \geq c_j} \pi_i(a)\sigma_j(e)(v_i \Leftrightarrow c_j) \Leftrightarrow \mu(a) \Leftrightarrow \psi(e). \tag{8}$$

We obtain the following first-order conditions which are necessary and sufficient for a

[9]Since it is the finance minister, and not the regulator, who levies the tax T, there is no danger of collusion between regulator and contractors.

unique and interior solution $a^*, e^* > 0$:[10]

$$\mathcal{W}_a = 0: \quad \sum_i \sum_j{}_{v_i \geq c_j} \; \pi_i' \, \sigma_j(e) \, (v_i \Leftrightarrow c_j) = \mu'(a), \tag{9}$$

$$\mathcal{W}_e = 0: \quad \sum_i \sum_j{}_{v_i \geq c_j} \; \pi_i(a) \, \sigma_j' \, (v_i \Leftrightarrow c_j) = \psi'(e). \tag{10}$$

The resulting investments a^* and e^* will be used as benchmarks to be compared with the actual investments resulting from the two contractors' Nash equilibrium at stage 2 of the game.

Finally, let us define a *first-best result.* It is attained if in the subgame-perfect equilibrium the prices $\{p_j\}$, chosen at date 1, induce both ex-ante and ex-post efficiency.

3 Regulation by means of a sequential mechanism

In this section it will be shown that the first best can be attained if at date 4 the regulator applies the following sequential mechanism:

(i) the regulator first asks the seller whether he wants to grant the license at p_j or not;

(ii) in a second step the regulator asks the buyer whether he makes a counteroffer or not. This counteroffer may refer to changes either in the trade price or in the no-trade price;

(iii) in a third step the seller accepts or rejects the counteroffer (if there is one) and decides whether to grant the license or not.

This sequential regulatory mechanism puts the contractors in the same legal position they would have attained if they had written an option contract á la Nöldeke and Schmidt (1995). Transferring the idea of an option contract to our regulatory setting raises several problems. Nöldeke and Schmidt assume that benefit, costs, and the relationship-specific investments are observable by both seller and buyer. This implies, inter alia, that it does not matter whether the seller or the buyer holds the option. In contrast, in the partially-private information case of this paper, the first best can only be attained if the seller is given the option, whence the informed party, the buyer, can make the perfect counteroffer. This makes clear that the proposed mechanism does not achieve the first best if both value and costs are private information. The problem of the perfect counteroffer will explicitly be shown when discussing ex-post efficiency (see footnote 11 below).

The proposed sequential mechanism runs counter to one of the most accepted paradigms of price regulation. The very formula of price-cap regulation $p \leq \overline{p}$ explicitly forbids

[10] Formally, the existence of an interior solution is ensured since expected welfare as defined in (8) is concave in both of its arguments and the Inada conditions are assumed to be fulfilled. The maximum is unique if one assumes $| W_{hh} | > | W_{hg} |, \; h, g \in \{a, e\}$.

upward renegotiation of the regulated price. On the other hand, this formula allows downward renegotiation. The sequential mechanism we propose a priori allows both upward and downward renegotiation. As will be shown, the regulated trade price will only be renegotiated upward, no downward renegotiation is ever needed to achieve the first best. Hence, this is the exact opposite of the usual price-cap paradigm.

3.1 Ex-post efficiency

Applying backward induction, we first deal with the contractors' decision on the granting of the license. At this stage of the game, date 4, the buyer is fully informed: he knows the benefit v_i and the costs c_j. The seller remains partially uninformed since he does not know v_i. The contractors would like to trade if

$$v_i \geq p_j \qquad \text{(buyer's condition)}, \tag{11}$$

$$p_j \geq c_j \qquad \text{(seller's condition)}. \tag{12}$$

As a consequence of nature's draw of benefit and costs, there are six different cases which we have to distinguish. In the first three cases the net benefit of the license is negative: ex-post efficiency requires that the license is not granted. As we shall see, this actually happens in our sequential mechanism. The second set of three cases refers to a positive net benefit and the agents decide in favor of granting the license.

(1) $v_i < c_j$

   (a) $p_j \leq v_i < c_j$
   In this case the seller is not interested in exercising the option. The buyer, who is interested in taking over at the initial contract terms, is willing to offer a higher trade price. However, his maximum offer would be $p_j = v_i$ and this is not enough to induce the seller to exercise the option. Hence, the buyer will not make such a meaningless counteroffer. The license is not granted in this case. Note that it is sufficient that the buyer knows v_i. There is no need for the seller or the regulator to know the precise benefit of the license. For the two of them it is sufficient to recognize that the buyer refrains from making a counteroffer.[11]

   (b) $v_i < p_j < c_j$
   In this case, the seller is not interested in exercising the option. The buyer is not interested in taking over. The license is not granted.

[11] It is cases like (1a) which are decisive for the impossibility to attain the first best by a buyer's option. The buyer would exercise his option and the seller's ideal counteroffer would be a no-trade price $p_0^R = p_{1j} - v_i$. However, the seller cannot make this counteroffer because he cannot observe v_i. Even worse, the seller cannot distinguish between case (1a), $p_j \leq v_i < c_j$, and case (2c), $p_j < c_j \leq v_i$. Hence, in both cases he will make the same counteroffer $\widetilde{p_0^R}$ which maximizes his profit over all possible realizations of v_i. In other words, he will trade-off his utility from no trade at some price $\widetilde{p_0^R}$ and from trade at price p_{1j} and this will violate ex-post efficiency.

(c) $v_i < c_j \leq p_j$

Here the seller wants to exercise the option. However, the buyer offers a higher no-trade price $p_0^R = p_{1j} - c_j$. Note that the buyer has higher utility if the license is not granted in spite of his having to pay the upwardly renegotiated price p_0^R: if the license is not granted, his payoff is $-p_{1j} + c_j$; if it is granted, the payoff is $v_i - p_{1j}$. The no-trade payoff exceeds the trade payoff since $c_j > v_i$. Given the buyer's counteroffer, the seller is indifferent between trade and no trade. Accordingly, he would prefer to trade, as implied by his decision rule (12). To prevent such an inefficiency, let us add a minor refinement: we assume that there is a small cost to using the courts to enforce the contract.[12] Hence, the seller accepts the counteroffer, does not grant the license, and the buyer pays the renegotiated no-trade price p_0^R.

(2) $v_i \geq c_j$

(a) $p_j > v_i \geq c_j$

The seller in the first step wants to exercise the option. The buyer in the second step could offer a lower trade price $p_{1j}^R = p_0 + c_j < p_{1j}$, which maximizes his utility and still leaves the seller interested in trade. However, the seller's best response in the third step would be to reject the buyer's offer and to inform the regulator that the license will be granted at the initially contracted price. Anticipating the seller's response, the buyer abstains from making a counteroffer and the license is granted at the initial price. The sequential mechanism prevents downward renegotiation.

(b) $v_i \geq p_j \geq c_j$

In this case the agents behave exactly as in case (2a); once again, the license is granted at the initially contracted price.

(c) $v_i \geq c_j > p_j$

Here the buyer wants to become a licensee, but the seller does not want to exercise the option. Hence, the buyer offers to pay more, namely $p_{1j}^R = p_0 + c_j > p_{1j}$. This makes the seller indifferent between selling or not, therefore he will accept the counteroffer and the license is granted at an upwardly renegotiated price.

[12]Alternatively, we could have assumed that the regulator intervenes in the case of this special counteroffer (and only this counteroffer) and rules that the license is not to be granted. Note that the regulator observes c_j and knows p_{1j}, so he can impose a special tie-breaking rule for this particular case.

3.2 Ex-ante efficiency

We now examine the Nash equilibrium at date 2 where both licensee and grid choose their relationship-specific investments for given initial prices $\{p_j\}$. The players maximize their utilities, anticipating the results of the renegotiation stage:[13]

$$U^B = \sum_i \sum_{j \atop v_i \geq c_j} \pi_i(a)\sigma_j(e)(v_i \Leftrightarrow c_j) \Leftrightarrow \sum_{j \atop p_j \geq c_j} \sigma_j(e)(p_j \Leftrightarrow c_j) \Leftrightarrow p_0 \Leftrightarrow \mu(a), \tag{13}$$

$$U^S = \sum_{j \atop p_j \geq c_j} \sigma_j(e)(p_j \Leftrightarrow c_j) + p_0 \Leftrightarrow \psi(e). \tag{14}$$

This is Nöldeke and Schmidt's (1995, 169) famous result, transferred to our case of partially-private information and J prices. Most striking is the buyer's utility. It is equal to welfare minus utility of the seller and this utility of the seller does not depend on the buyer's investment decision. This is rooted in the special renegotiations that lead to prices which only depend on costs, and therefore cannot be influenced by the buyer.[14] Moreover, the initially contracted prices never depend on any single realization of the benefit v_i, so the buyer cannot exert any influence on the probability that a particular price is realized.

Maximizing the buyer's utility with respect to his investments yields the same first-order condition as maximizing welfare: the buyer behaves like a welfare maximizer, whatever prices the regulator has chosen. Therefore, both-sided efficiency results when the seller acts welfare-optimally. How can he be induced to do so? Maximizing the seller's utility with respect to his investments yields the following marginal condition:

$$\sum_{j \atop p_j \geq c_j} \sigma_j'\,(p_j \Leftrightarrow c_j) = \psi'(e). \tag{15}$$

Equality of the seller's Nash investments and his welfare-optimal investments requires the simultaneous validity of the Nash equation (15) and the benchmark equation (10), under the assumption that the buyer's investments are welfare optimal. This requires:[15]

$$\sum_{j \atop p_j \geq c_j} \sigma_j'\,(p_j \Leftrightarrow c_j) \;=\; \sum_i \sum_{j \atop v_i \geq c_j} \pi_i(a)\; \sigma_j'\;(v_i \Leftrightarrow c_j). \tag{16}$$

[13] The detailed derivation of these utilities is presented in an appendix, sent to the reader on request.

[14] This is different in the case of at-will contracts à la Hart and Moore (1988), where downward renegotiation leads to a trade price $p^R_{1j} = p_{1j} + v_i$ if $p_j > v_i \geq c_j$ (case 2a).

[15] Compare the seller's Nash investments e^N and his welfare-optimal investments e^*. Since $\psi(e)$ is monotonically increasing in e, a necessary and sufficient condition for $e^N = e^*$ is a set of prices $\{p_j\}$ which equates the left-hand sides of (15) and (10). This equalization leads to condition (16). As mentioned in the text this condition is evaluated at $a = a^*$.

Note that both sides of equation (16) are strictly positive since they have to be equal to $\psi'(e)$ which we have assumed to be strictly positive for interior solutions (and the benchmark is fulfilled for interior values of e and a).

3.3 Regulatory pricing policies

We will concentrate on two particularly appealing policies which fulfill equation (16) and hence guarantee the achievement of the first best by both-sided investments.

Proposition 1 (bunching). The first best can be attained by a single price $p = p_j$ for all j. This price is unique.

Proof. Consider equation (16) for $p_j = p\ \forall j$. Recall that $a = a^*$ always holds. (a^*, e^*) is a Nash equilibrium of the game if there is an optimal price p which fulfills (16). The RHS of (16) has a positive constant value. The LHS is continuous and by the monotone likelihood ratio property it is strictly increasing in the price p although not everywhere differentiable. Using monotonicity, in order to prove the existence of a unique optimal price we have to find values of p which lead to a LHS which falls short of or exceeds the RHS. We start by considering $p \leq c_1$. In this case $LHS = 0 < RHS$, that is, underinvestment occurs. Next, let us examine $p \geq v_I$. After substituting any such high price, LHS becomes $\Leftrightarrow\Sigma_j \sigma'_j c_j$ (recall $\Sigma_j \sigma'_j = 0$). Now transform RHS into $\Sigma_i \Sigma_j \pi_i \sigma'_j (v_i \Leftrightarrow c_j) \Leftrightarrow \Sigma_i \Sigma_{j(v_i<c_j)} \pi_i \sigma'_j (v_i \Leftrightarrow c_j)$. The first term is equal to $\Leftrightarrow\Sigma_j \sigma'_j c_j$. For the second term we have $\Sigma_{j(v_i<c_j)} \sigma'_j [v_i \Leftrightarrow c_j] > 0$ for all i, because $[v_i \Leftrightarrow c_j]$ is negative and decreasing in j, and $\Sigma_{j(v_i<c_j)} \sigma'_j \leq 0$ and σ'_j decreasing in j (from the monotone likelihood ratio property).[16] Hence, for $p \geq v_I$, we have $LHS > RHS$ and overinvestment results. Obviously, from the intermediate-value theorem, there must be a unique p^* which ensures the equation (16). □

The reader may be surprised that the first best can be achieved if the regulator 'throws away information' and chooses one price only although he could choose J different prices. However, where it is necessary for the achievement of the first best, the renegotiation changes the single initial price into many different prices.

Proposition 2 (reward for low costs). The first best can be attained if all prices are equated to costs except for the lowest price which exceeds the respective costs by a premium.

[16] In other words: for high cost realizations the negative term in brackets is multiplied with negative σ'_j and (at most) for low cost realizations with positive σ'_j. The absolute value of the term in brackets is increasing in j. Hence, the sum of the products must be positive.

Proof. Substitute $p_j = c_j$, $j = 2, ..., J$ into (16) and solve for p_1,[17]

$$p_1 = c_1 + (1/\sigma_1') \sum_{\substack{i \\ v_i \geq c_j}} \sum_j \pi_i(a)\, \sigma_j'\, (v_i \Leftrightarrow c_j). \tag{17}$$

It can directly be seen that $p_1 > c_1$ since the far right correction term is stricly positive: $\sigma_1' > 0$ and $\sum_{\substack{i \\ v_i \geq c_j}} \sum_j \pi_i(a)\, \sigma_j'\, (v_i \Leftrightarrow c_j) > 0$ because it is the right-hand side of (16). □

Before concluding this subsection it may be mentioned in passing that there are many other pricing policies which fulfill equation (16), for instance a pricing policy which sets $p_j = 0$ for all but one price or a policy which equates all low-cost prices to the respective costs and then stipulates a penalty for high costs. (The latter policy, however, might drive the seller into bankruptcy. Hence, the reward for low costs is a preferable policy.)

3.4 Remark: relation to the literature

As suggested by one of the referees, this remark relates the present paper to Ausubel and Deneckere (AD, 1989). They investigate how the many equilibria of a direct mechanism can be reduced if special assumptions on the sequencing of bargaining are made in an extensive form. They deal with a trade model where the seller's valuation is common knowledge, whereas the buyer's valuation is private information, which informational setting is similar to ours.[18] However, they do not deal with relationship-specific investments. If the AD paper is able to throw some light on the present paper (or vice versa), then it is their theorem 4 which might help to a better understanding of our regulatory mechanism. This theorem shows that efficient trade is the unique sequential equilibrium outcome of a game in which the informed party makes offers and the uninformed party either accepts or rejects the offers. This corresponds to our setting, where offers with respect to prices are only made by the informed buyer. However, there is a main difference between theorem 4 of AD and the present paper. In AD prices are only fixed ex post in negotiations on the sharing of surplus. Therefore, efficient trade is achieved if the informed buyer has all the bargaining power and formulates his offers in such a way that he appropriates all gains from trade. In the present paper, prices are contracted ex ante and re(!)negotiated ex post. The ex-ante contract must be written to give correct investment incentives not only to the informed buyer, but also to the uninformed seller. The informed buyer must not get all the gains from trade, because this would destroy all investment incentives of

[17] The probabilities π_i depend on the variable a which the regulator cannot observe. However, in (17) only $\pi_i(a^*)$ enters and a^* can directly be calculated from the benchmark welfare optimum without any knowledge of the buyer's actual choice of investment.

[18] This might also help those readers who dislike the assumption of observable costs, which we made following the Laffont-Tirole tradition. AD build on a large literature where cost observability is a common assumption.

the seller. The prices needed to ensure both-sided efficient investments effectively shift part of the bargaining power to the uninformed seller.

4 Regulation if renegotiation is forbidden

Upward and never downward renegotiation is the striking feature of the proposed sequential regulatory mechanism. This mechanism attains the first best. However, upward renegotiation of regulated prices is an unusual concept. Any conventional regulator will feel uneasy about this. Let us therefore consider a conventional regulatory scheme which forbids any renegotiation. Will such a scheme be successful in our partially-private information setting?[19] We assume that the regulator makes the following provisions. Grid and licensee write an incomplete contract adopting the prices which the regulator has announced for any single cost realization. The enforcement of the contract is regulated as follows: when the veil of uncertainty about benefits and costs has been lifted, *the court enforces the original contract if at least one contractor wants to trade at the initial terms of this contract.*[20] This implies that grid and licensee can withdraw from the contract in mutual agreement. It also implies that the initially contracted regulated prices must not be renegotiated. Unfortunately, we shall see that this regulatory scheme cannot guarantee the first best for all possible benefit-cost realizations.

4.1 Ex-post efficiency

The players' objectives are unchanged: the buyer would like to trade if the benefit exceeds the price, the seller if the price exceeds the costs. However, renegotiation is now forbidden by the regulator, and the license is to be awarded at the price p_j if at least one party insists on the fulfillment of the contract. This is always the case if $v_i \geq c_j$, whatever the regulated price. In other words: the only efficiency concern in our setting is trade occuring when it should not. Once again we solve this problem by assuming that there is a small cost to using the courts to enforce the contract. As we shall see later, this assumption is necessary to attain ex-post efficiency by a regulated contract through prices which also induce ex-ante efficiency. Consider, for instance, a regulation which has set $p_j = c_j$. In such a case, the seller will not unilaterally enforce the contract (although he is willing to trade). Hence, there will be trade whenever the buyer wants to trade ($v_i \geq p_j = c_j$). Otherwise, when $v_i < p_j = c_j$, the buyer will not want to trade and the seller will not go to the court although he would be willing to trade. This guarantees ex-post efficiency.

[19]Forbidding only upward renegotiation and allowing downward renegotiation fails, as the author has shown in a previous version of this paper which can be sent to the reader on request.

[20]In contrast to Nöldeke and Schmidt (1995), one-sided options to trade result *endogenously* and are not initially contracted.

4.2 Ex-ante efficiency

We now examine the Nash equilibrium at date 2 where both licensee and grid choose their relationship-specific investments for given initial prices $\{p_j\}$. Licensee and grid maximize their objective functions

$$\begin{aligned} U^B &= \sum_i \sum_{\substack{j \\ v_i \geq c_j}} \pi_i(a)\sigma_j(e)(v_i \Leftrightarrow p_j) \Leftrightarrow p_0 \Leftrightarrow \mu(a), && (18) \\ U^S &= \sum_i \sum_{\substack{j \\ v_i \geq c_j}} \pi_i(a)\sigma_j(e)(p_j \Leftrightarrow c_j) + p_0 \Leftrightarrow \psi(e). && (19) \end{aligned}$$

Differentiation with respect to the investments yields unique positive Nash-equilibrium investments which depend on the initial prices $\{p_j\}$. Are there initial prices which induce Nash investments which are just equal to the welfare-optimal ones? This requires the simultaneous validity of the Nash marginal conditions and the respective benchmark conditions. After some simplifications, this requires:

$$\begin{aligned} \sum_i \sum_{\substack{j \\ v_i \geq c_j}} \pi_i' \, \sigma_j(e) \, c_j &= \sum_i \sum_{\substack{j \\ v_i \geq c_j}} \pi_i' \, \sigma_j(e) \, p_j, && (20) \\ \sum_i \sum_{\substack{j \\ v_i \geq c_j}} \pi_i(a) \, \sigma_j' \, v_i &= \sum_i \sum_{\substack{j \\ v_i \geq c_j}} \pi_i(a) \, \sigma_j' \, p_j. && (21) \end{aligned}$$

The results are only briefly treated in this paper; a more elaborated version is contained in an appendix, sent to the reader on request.

Proposition 3. If the benefit-cost realizations do not overlap ($v_1 > c_J$), the first best can be attained by prices $p_j = c_j \; \forall j$ with one exception, which can be used as a reward for low costs or as a penalty for high costs.

Proof. Since $v_1 > c_J$, equation (20) can be rewritten as $\sum_{i=1}^I \pi_i' \sum_{j=1}^J \sigma_j c_j = \sum_{i=1}^I \pi_i' \cdot \sum_{j=1}^J \sigma_j p_j$. Recall $\sum_{i=1}^I \pi_i' = 0$. Hence, equation (20) holds always, whatever prices are chosen, and the buyer will always invest efficiently. Equation (21) can be used to give the correct incentives for the seller: set $p_j = c_j \; \forall j \neq k$ and solve (21) for p_k. □

Proposition 4. If benefit-cost realizations overlap, and $c_1 < ... < c_m < v_1 < c_n < ... < c_J$, the first best can be attained by high-cost prices $p_j = c_j, \; j = n, ..., J$ and a unique price p for the low-cost realizations $j = 1, ..., m$, which is a reward for low costs.

Proof. Substitute the high-cost prices into (20) and take account of $v_i > c_m$. Then (20) can be rewritten as $\sum_{i=1}^I \pi_i' \sum_{j=1}^m \sigma_j c_j = \sum_{i=1}^I \pi_i' \sum_{j=1}^m \sigma_j p_j$. Recall $\sum_{i=1}^I \pi_i' = 0$. Hence, the buyer invests efficiently whatever the low-cost prices. Choose (21) to determine these low-cost prices, for instance one single price for all low-cost realizations. □

Proposition 5. If benefit-cost realizations overlap, but $v_1 < ... < v_g < c_1 < v_h < ... < v_I$, the first best cannot be attained as long as both agents invest. If only the buyer invests, he can be induced to efficiency.

Proof 5.1 (Both-sided inefficiency). The buyer will invest efficiently if $p_j = c_j \; \forall j$, see equation (20). However, this pricing policy will not fulfill (21) for arbitrarily chosen exogenous realizations of v_i and c_j. If prices deviate from costs, however, (20) can only hold if at least one price exceeds the respective cost realization. If this cost realization is drawn by nature, the seller will enforce the contract, even if $v_i < c_j$ which is always possible since $c_1 > v_g > ... > v_1$. Hence, ex-post efficiency is violated. □

Proof 5.2 (One-sided efficiency). Assume $\sigma(e) = \sigma$, whence the seller will not invest, $e = 0$. Then, prices $p_j = c_j \; \forall j$ fulfill (20). □

5 Conclusion

In this paper regulation aims at solving the hold-up problem which typically arises in the case of relationship-specific investments whose costs are sunk when the final decision on trade is taken. We show that a sequential regulatory mechanism guarantees the first best. This mechanism works similar to a Nöldeke-Schmidt option contract, although our paper assumes a more complicated information setting. The investments and the costs of the license are observed by both seller and buyer, whereas the benefit of the license is private information of the buyer. The regulator cannot observe the investments and the benefit, however, he can observe the cost realizations. This informational setting has been chosen because some of the best-known revelation mechanisms, when applied to the hold-up problem, fail to achieve the first best in cases of partially-private information.

The proposed sequential mechanism questions the price-cap paradigm of regulation: price caps explicitly forbid upward renegotiation of regulated prices, whereas downward renegotiation is allowed. In contrast, the application of the sequential regulatory mechanism requires upward but never downward renegotiation. Various pricing policies can be used to attain the first best by implementing the sequential regulatory mechanism. By way of example, one single and unique price could be set, giving up ex-ante differentiation of regulated prices. A further possibility would be prices which are equal to costs unless nature draws the lowest cost realization which triggers a reward for the seller.

Finally it is shown that in the partially-private information setting of this paper the regulator cannot in general guarantee the achievement of the first best if renegotiation is forbidden.

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