◆ *Iván Major–Károly M. Kiss* ◆

INTERCONNECTION AND INCENTIVE REGULATION IN NETWORK INDUSTRIES

The price regulation of network industries has changed tremendously all over the world recently. Theoretical contributions specifically advocate and telecommunications, energy and other market regulators in various parts of the world practice cost-based pricing for inter-firm network access services. Cost-based pricing is performed under the assumption that the regulator has perfect information regarding the costs of producing the services. We show that – under fairly general conditions – cost-based pricing creates incentives for regulated firms *not* to improve their efficiency. Allowing for information asymmetry between the regulator and the regulated firms, we find that incentive regulation will eliminate the adverse effect of cost-based pricing on the firms' efficiency and on social welfare.

INTRODUCTION

The regulation of network industries has received ever greater attention during the current financial and economic crisis than before. This paper addresses the regulation of interconnection prices for firms with interconnected networks with perfect, and with imperfect and asymmetric information. It unites two separate lines of previous analyses. On the one hand, important works by *Armstrong–Doyle–Vickers* [1996], *Laffont–Rey–Tirole* [1998a,b); *Carter–Wright* [1999, 2003] and *Armstrong* [2002], as well as studies by *De Bilj–Peitz* [2002], *Peitz* [2005] and numerous others address the issue of interconnection and termination charges under the assumption that the regulator has perfect information about the true costs of providing inter-firm network access services. On the other hand, the literature is equally extensive on the nature and consequences of asymmetric cost information between the regulator and the regulated firm. The seminal work on regulating a firm with unknown costs was written by *Baron–Myerson* [1982]. Important contributions were made, among others, by Laffont – Tirole [2000] and *Laffont–Martimort* [2002].[1] However, we are aware of only a few studies that combined these two lines of investigation.[2] Some authors did not see the need for doing so. For example, *Armstrong* [2002] noted that “While it is clear that imperfect regulatory knowledge of costs and

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[1] *Armstrong–Sappington* [2007] offer an overview of the issues of imperfect information in regulated industries.

[2] See, for instance, *Sappington* [1980], *Stefos* [1990] and *Blackmon* [1994].

the potential for cost reduction has an important impact on regulatory policy, the interaction of these features with the access pricing problem does not often seem to generate many new insights" (p. 380). Believing that perfect regulatory knowledge was an adequate assumption, Armstrong then went on to propose that the regulator should base inter-firm network access prices on "estimated efficient costs," or costs computed from engineering models, or benchmarking.

The principle of cost-based pricing has long dominated the regulatory approaches to pricing end user services. In addition to the major carriers' own cost models, North American regulators required the construction of elaborate service cost simulation models for various levels of service aggregation as early as the 1970s. When, after opening up the market to competition in telecommunications and other utilities markets, the regulation of inter-firm network access prices became a regulatory task of critical importance, cost-based pricing quickly found these industries as a new field of application. Regulators began to demand that network operators provide access to their network for other service companies for charges that were based on long run incremental costs.

Many difficulties are inherent in this approach.[3] We show in this paper that cost-based pricing may signal incentives to firms *not* to improve the efficiency level of interconnection. The adverse effects of cost-based price regulation work through two channels. First, even if the regulator had perfect information about the service providers' call termination costs and based termination charges on those costs, service providers would not be induced to attain high efficiency because a higher efficiency in network interconnection would not result in higher profits for them. This is a direct consequence of the complex cross-price effects in inter-firm services.[4] Second, the adverse effect of cost-based pricing on service providers' efficiency is exacerbated if the regulator's information about the firms' cost is imperfect.

In reality, regulators can never perfectly know the true costs of network access services. More is involved than the informed party's unwillingness to disclose private information, or biases due to the unavoidable arbitrariness of some elements of cost allocation. The firm and the regulator may have some misperceptions about what the other party knows or infers from the information they both possess. For instance, a firm may assume, albeit mistakenly, that the regulator is also aware of some specific information about efficient operation that the firm previously acquired. Consequently, the firm would expect the regulator to incorporate this piece of information into his regulatory decision, although this will not, in fact, occur. Thus, the firm would adjust its output decision to a false assumption. *Madarász* [2007]

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[3] *Laffont–Tirole* [2000] briefly mention the shortcomings of cost-based pricing.

[4] *Hansen* [2005] addresses a similar issue that he labels "tariff mediated network externalities." He shows that a low-cost firm will attain a smaller, while a high-cost firm will have a larger market share in equilibrium than would be rational from an efficiency point of view.

labelled this kind of assumption "information projection." The opposite may also happen. The firm may ignore important portions of cost accounting information and assume that the regulator is equally ignorant. According to Madarász, this is "ignorance projection." Cost-based pricing may give rise to simultaneous cases of "information projection" and "ignorance projection". As a result, cost-based pricing may do more harm than good.

Regulatory agencies have recently also recognised some of the weaknesses of a cost-based regulatory design and they started applying "bottom-up" benchmark models in their effort to find efficient prices. Bottom-up models establish the lowest feasible level of costs for each element of the network and then aggregate these cost components up to the level of end user services. We show in this paper that bottom-up benchmarking is not a solution for regulatory games if the firms operate with different marginal costs. In addition, bottom-up cost models may also fare poorly if one of the parties has private information. The more informed party – usually the service provider – can rightfully claim that its actual conditions of business operation differ widely from what the regulator assumes when it constructs an efficiency model of a hypothetical company. These disputes between the firm and the regulator usually end up in the courts where the regulator can rarely win his case. We use the example of the telecommunications industry, but our findings can be easily generalised for other network industries such as energy distribution, transportation, water supply, and postal services, where there is two-way network interconnection between firms.

Our point of departure is a model of customers' choice between service providers, similar to the one presented by *Laffont et al.* [1998*a*], [1998*b*]. We diverge from their model on one important point: we assume that a customer's valuation of network size and each customer's demand for calls are additively separated. Our assumption is supported by empirical observations that indicate that customers may assign a greater value to a service provider with a larger network than to a service provider with a smaller network, but each customer's actual demand for calls will depend on the calling price rather than on the firms' size. In our model, the firms' market share will also be a function of customers' demand for intranet and for off-net calls, but our approach renders it feasible to derive analytical results and conclusions. In addition, we relax the assumption of Laffont et al. about perfect information in the later part of the paper, and develop a different model in which asymmetric information between service providers and regulators is assumed. We shall show that incentive regulation with imperfect information is not merely a more realistic assumption than assuming perfect information of the regulator, but that it also eliminates the adverse effects of cost-based pricing on the firms' efficiency.

The regulatory model of interconnection with imperfect information conveys important policy implications. We demonstrate that incentive regulation extends the proper incentives to firms to improve efficiency and that it results in a smaller social welfare loss than cost-based pricing or bottom-up cost accounting. Principal-agent models of price regulation are more "knowledge intensive" but less time consuming with regard to monitoring the costs of different services than cost accounting. Most importantly, a regulatory mechanism that takes into account the existence of asymmetric information between the regulator and the regulated firm induces cooperation between the contracting parties, while cost-based pricing inevitably brings about conflict between the regulator and the regulated firm.

The structure of the paper is as follows. The assumptions are outlined in section 2. The benchmark case of regulation with perfect information and cost-based pricing is presented in section 3. Section 4 is devoted to the description of a model of incentive regulation with two different efficiency types of the regulated firms. We solve the model in section 5. The results are compared to those of other pricing policies, and the main conclusions are drawn in section 6.

ASSUMPTIONS

Two firms (denoted by subscripts 1 and 2) are assumed to operate in a market of telecommunications services. They offer differentiated services to subscribing end users and in doing so, they compete in prices. For simplicity's sake, we shall work with a one period model where end users do not migrate between service providers, that is, we do not deal with the issue of switching costs. Subscribers initiate and receive intra-firm and inter-firm calls. Intra-firm calls are initiated and terminated in the same network, while inter-firm calls are terminated in the other network. There are three kinds of prices: *subscription* fees f_1 and f_2 that customers must pay in order to gain access to the network of firms 1 and 2, respectively; usage sensitive *intra-firm* calling prices p_1 and p_2; and usage sensitive *inter-firm* calling prices $\hat{p}_1$ and $\hat{p}_2$.[5] Inter-firm calling prices $\hat{p}_1$ and $\hat{p}_2$ include *termination* charges a_1 and a_2, respectively. These are paid by each firm to the other firm for using the other firm's network in order to terminate inter-firm calls. There are no separate transit charges since there are only two networks. All subscription and calling prices are unregulated. Termination charges are subject to regulation.

Subscribers have an identical valuation $0 < V(s_i) < s_i$ for belonging to network i of size s_i, where s_i is the number (mass) of subscribers who subscribe to network i. $\sum_i s_i$ is normalised to one and it also denotes the market share of firm i. Hence, for two firms, $s_1 + s_2 = 1$. For simplicity's sake, subscriber valuation is given by $V(s_i) = s_i V$.

A customer chooses between the two networks based on his valuation of network size and on the monetary utility, $u(p, \hat{p}, f)$, he can gain from using the services of each network. We assume that the customer's valuation of network size and his

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[5] The total price a customer pays for subscribing to a network then for using its services is similar to the two-part tariff introduced in *Carter–Wright* [2003] and in *Valletti–Cambini* [2005].

monetary utility from using the network are additive in his total utility. The intuition behind this assumption is that a customer's decision of how many calls he will make depends only on the price of placing calls. Network size matters when a customer chooses a service provider because the size of the network will affect his utility through the intranet and off-net calling prices he expects to pay. Market shares will be functions of customers' total utility and may be derived from a simple, slightly modified price competition model of consumer choice *à la* Hotelling.

The representative customer's demand for intranet calls is given by $d(p)$, while the mass of a customer's inter-firm calls is $\hat{d}(\hat{p})$. A subscriber's consumer surplus from a mass of $d(p)$ intranet calls is denoted by $v(p)$. It is assumed that $v'(p) \equiv -d(p)$ Similarly, a subscriber's consumer surplus from a mass of $\hat{d}(\hat{p})$ inter-firm calls is denoted $\hat{v}(\hat{p})$, and $\hat{v}' \equiv -\hat{d}(\hat{p})$ by assumption. We assume that subscribers' choice between networks is also influenced by their non-price preferences for service providers. A customer's "distance" from his most preferred network will be denoted θ. We assume that θ is uniformly distributed on the unit interval between firm 1 and firm 2: $\theta \in [0,1]$ may be understood as the factor of substitution between network 1 and network 2. Thus, a subscriber's total utility – or total consumer surplus, denoted *CS* – from choosing network 1 or network 2 becomes

$$\begin{aligned} U_1 &= CS_1 = s_1 V + v_1(p_1) + \hat{v}_1(\hat{p}_1) - f_1 - \theta, \text{ or} \\ U_2 &= CS_2 = (1 - s_1)V + v_2(p_2) + \hat{v}_2(\hat{p}_2) - f_2 - (1 - \theta) \end{aligned} \tag{1}$$

The marginal subscriber between networks 1 and 2 will be the person for whom

$$s_1 V + v_1(p_1) + \hat{v}_1(\hat{p}_1) - f_1 - \theta^* = (1 - s_1)V + v_2(p_2) + v_2(\hat{p}_2) - f_2 - (1 - \theta^*), \tag{2}$$

or

$$v_1(p_1) + \hat{v}_1(\hat{p}_1) - f_1 - s_1(1 - V) = v_2(p_2) + \hat{v}_2(\hat{p}_2) - f_2 - (1 - s_1)(1 - V), \tag{3}$$

where θ^* denotes the marginal customer's distance from firm 1. (With uniform distribution, $\theta^* = s_1$ will also hold.)

The indifference condition in (2) gives

$$\begin{aligned} s_1 &= \frac{v_1(p_1) - v_2(p_2) + \hat{v}_1(\hat{p}_1) - \hat{v}_2(\hat{p}_2) + f_2 - f_1}{2(1 - V)} + \frac{1}{2}, \text{ and} \\ s_2 &= 1 - s_1 = \frac{v_2(p_2) - v_1(p_1) + \hat{v}_2(\hat{p}_2) - \hat{v}_1(\hat{p}_1) + f_1 - f_2}{2(1 - V)} + \frac{1}{2} \end{aligned} \tag{4}$$

Service providers operate with constant, but different marginal costs in each segment of the service. This assumption implies that it is in a society's interest to purchase and use the services of the less efficient company, too, for it still increases social welfare. Consequently, uniform regulated prices would not be feasible in the short run because the less efficient company would incur losses and it would cease to provide a socially useful service. Fixed costs are disregarded because they do not affect the optimal level of service.

c_i^F denotes the marginal (unit) cost of connecting a new subscriber to network i.[6] Firm i (i = 1, 2) incurs a total marginal cost of $c_i = c_i^O + c_i^T$ by providing on-net (intranet) calls to its own subscribers – where c_i^O denotes the marginal cost of call origination, while c_i^T labels the marginal cost of call termination – but the firm incurs only the unit cost c_i^T by terminating the off-net calls for subscribers of the other firm, respectively.

Firm i's total profit from serving a mass of s_i customers with on-net calls and a mass of s_j customers with inter-firm calls can be written as

$$\pi_i = \underbrace{s_i\Big(\big(p_i - c_i^O - c_i^T\big)d_i(p_i) + \big(\hat{p}_i - c_i^O - a_j\big)\hat{d}_i(\hat{p}_i) + f_i - c_i^F\Big)}_{\text{profit from internal subscribers}} + \underbrace{s_j\big(a_i - c_i^T\big)\hat{d}_j(\hat{p}_j)}_{\substack{\text{profit from call termination} \\ \text{for external customers}}}. \tag{5}$$

The total profit for the whole industry thus becomes

$$\Pi = \pi_1 + \pi_2 = s_1\Big(\big(p_1 - c_1^O - c_1^T\big)d_1(p_1) + \big(\hat{p}_1 - c_1^O - c_2^T\big)\hat{d}_1(\hat{p}_1) + f_1 - c_1^F\Big) + \\ + s_2\Big(\big(p_2 - c_2^O - c_2^T\big)d_2(p_2) + \big(\hat{p}_2 - c_2^O - c_1^T\big)\hat{d}_2(\hat{p}_2) + f_2 - c_2^F\Big) \tag{6}$$

REGULATING INTERCONNECTION WITH PERFECT INFORMATION: COST-BASED PRICING FOR CALL TERMINATION

It is assumed to be in a society's interest to control the firms' monopoly power over interconnection in order to foster competition in end user services. In fact, such regulation exists in numerous countries, where the regulator sets an upper limit on the call termination charge a. We assume that the regulator wants to maximise social welfare (W) – measured as total consumer surplus plus total industry profit – in the regulated segment of the market, subject to some constraints. The regulator's valuation over gross economic surplus is concave with the usual properties: $W' > 0$, $W'' \leq 0$. Thus, the regulator's objective function can be written as

$$\max_{a_i,\, a_j} W = \max_{a_i,\, a_j}\{s_1 CS_1 + s_2 CS_2 + \Pi\}, \tag{7}$$

where Π is total industry profit as described in (6) and CS_i is the net consumer surplus enjoyed by a subscriber to network i.

When firms find their optimal calling prices (p_i, $\hat{p}_i$) and subscription fee (f_i) by maximising profits, they take into account the termination fee a_i that will be set by the regulator. The first order conditions of the companies' profit maximum in equation (5) are as follows:

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[6] By this, we implicitly assume that service providers cannot extract all consumer surplus from new subscribers accessing their network.

$$\frac{\partial \pi_i}{\partial p_i} = \frac{\partial s_i}{\partial p_i}\tilde{\pi}_i + s_i d_i + s_i\left(p_i - c_i^O - c_i^T\right)\frac{\partial d_i}{\partial p_i} = 0, \tag{8}$$

$$\frac{\partial \pi_i}{\partial \hat{p}_i} = \frac{\partial s_i}{\partial \hat{p}_i}\tilde{\pi}_i + s_i \hat{d}_i + s_i\left(\hat{p}_i - c_i^O - a_j\right)\frac{\partial \hat{d}_i}{\partial \hat{p}_i} = 0, \tag{9}$$

$$\frac{\partial \pi_i}{\partial f_i} = \frac{\partial s_i}{\partial f_i}\tilde{\pi}_i + s_i = 0, \tag{10}$$

where $\tilde{\pi}_i = \left(p_i - c_i^O - c_i^T\right)d_i\left(\hat{p}_i - c_i^O - a_j\right)\hat{d}_i + f_i - c_i^F$ is firm *i*'s profit from one of its own customers. Using these conditions and the market share equation in (4), we have

$$p_i^* = c_i^O - c_i^T, \tag{11}$$

$$\hat{p}_i^* = c_i^O - a_j, \tag{12}$$

$$f_i^* = \frac{v_i(p_i) - v_j(p_j) + \hat{v}_i\left(\hat{p}_i(a_j)\right) - \hat{v}_j\left(\hat{p}_j(a_i)\right) + 2c_i^F + c_j^F}{3} + 2(1 - V). \tag{13}$$

Substituting equation (13) into equation (4) yields the following market shares:

$$s_i^* = \frac{v_i(p_i) - v_j(p_j) + \hat{v}_i\left(\hat{p}_i(a_j)\right) - \hat{v}_j\left(\hat{p}_j(a_i)\right) + c_j^F + c_i^F}{6(1 - V)} + \frac{1}{2}. \tag{14}$$

Since the regulator knows how firms solve their optimisation problem, he will use the firms' profit maximising prices to obtain optimal termination fees that will maximise total social welfare.[7] Substituting equations (11) and (12) into the regulator's objective function in (7) gives

$$\begin{aligned} W = {} & s_1\left[(a_2 - c_2^T)\hat{d}_1 - c_1^F + v_1(p_1) + \hat{v}_1\left(\hat{p}_1(a_2)\right)\right] + \\ & + s_2\left[(a_1 - c_1^T)\hat{d}_2 - c_2^F + v_2(p_2) + \hat{v}_2\left(\hat{p}_2(a_1)\right)\right] \end{aligned}, \tag{15}$$

where

$$(a_2 - c_2^T)\hat{d}_1 - c_1^F + v_1(p_1) + \hat{v}_1\left(\hat{p}_1(a_2)\right) = w_1,$$

and

$$(a_1 - c_1^T)\hat{d}_2 - c_2^F + v_2(p_2) + \hat{v}_2\left(\hat{p}_2(a_1)\right) = w_2 \tag{15a}$$

are economic surpluses at the firms' profit maximising prices per each subscriber in networks 1and 2, respectively.

Note that $w_1 = w_2$ must hold, otherwise the regulator would alter the termination charges in a way that would direct customers away from the network that yields lower economic surplus and toward the other network that offers a higher economic surplus per customer. For instance, if $w_1 > w_2$, then the regulator should reduce a_2,

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[7] Our results would not change if the regulator established the cost-based termination fee at $a_i = c_i^T$ and firms maximised profits by knowing the regulated termination charges.

the termination fee he had set to firm 2 (and/or he should increase a_1) in order to direct customers away from network 2 and toward network 1. However, a reduction of a_2 will reduce economic surplus at network 1. The adjustment of termination fees continues until $w_1 = w_2$. From this result and from $s_1 + s_2 = 1$ it follows that a_i will maximise total social welfare in equation (15) if total net surplus per consumer, $w_i = (a_j - c_j^T)\hat{d}_i - c_i^F + v_i(p_i) + v_i\left(\hat{p}_i(a_j)\right)$ attains its maximum at a_i^*. The first order condition of social welfare maximum is

$$\frac{\partial w_i}{\partial a_i} = \hat{d}_j + (a_i - c_i^T)\frac{\partial \hat{d}_j}{\partial a_i} - \hat{d}_j = 0, \tag{16}$$

which yields

$$a_i^* = c_i^T. \tag{17}$$

Based on the above results we can formulate our first proposition.

PROPOSITION 1 • *Regulated cost-based pricing of call termination cannot be reconciled with competitive (unregulated) calling prices and subscription fees if companies operate with different marginal costs. Cost-based call termination prices will punish the efficient firm for its market share and its subscription fee will be smaller, consequently, its profit will be lower than if this firm remained less efficient. Thus, cost-based pricing of call termination will extend a "perverse" incentive to service providers that they should not offer call termination at efficient costs.*

Proof • *It is easy to see from equation* (14) *that describes the market shares of the firms, that firm i's market share increases in its own termination charge a_i, but its market share is a decreasing function of the other firm's termination charge a_j:*

$$\frac{\partial s_i^*}{\partial a_i} > 0 \ and \ \frac{\partial s_i^*}{\partial a_j} < 0. \tag{18}$$

Equation (17) *above shows the profit maximising call termination charges. Since $a_i < a_j$ because $c_i^T < c_j^T$ by assumption, it follows from equations* (15) and (18) *that $s_i^* < s_j^*$.*

In addition, it can be seen from equations (11), (12) *and* (13) *that give the profit maximising calling charges and subscription fees, that firms will earn positive profits only on subscription. It is obvious from equation* (13) *that firm i's profit maximising subscription fee f_i^* increases in its own termination charge a_i, but it decreases in the other firm's termination charge a_j.*

$$\frac{\partial f_i^*}{\partial a_i} > 0 \ and \ \frac{\partial f_i^*}{\partial a_j} < 0 \tag{19}$$

Consequently, if $a_i < a_j$ because $c_i^T < c_j^T$, then $f_i^* < f_j^*$. Since $\frac{\partial \pi_i}{\partial f_i} > 0$ in the profit equation (5), *it follows from $f_i^* < f_j^*$ that $\pi_i(a_i^*) < \pi_j(a_j^*)$.* ■

Proposition 1 shows that the efficient firm will lose, while the inefficient firm will gain in terms of market share and profits with cost-based pricing of call termination. Consequently, it is not in a firm's interest to invest in efficiency improvements. In case the regulator does not know the companies' true costs of providing interconnection, or cost information is "noisy" – that is, the regulator can know the firms' true costs only with some probability – the lack of the regulator's perfect information will exacerbate the effects of "perverse" incentives under cost-based pricing as we shall show in the next sections.

REGULATION IN THE PRESENCE OF MORAL HAZARD AND ADVERSE SELECTION

Firms do not have the incentive to improve their cost efficiency if regulators of telecommunications companies exercise cost-based pricing of network interconnection (call termination) as we have shown above. In addition, cost-based pricing requires that regulators possess perfect (noiseless) information of each firm's termination costs. However, information about the companies' effort level to increase their efficiency and about the true cost of service provision is the firms' valuable private information that the firms are not willing to disclose voluntarily. If the regulator incurs large expenses with collecting detailed firm level information and he cannot be certain that the information he acquired is reliable, the adverse effects of cost-based pricing are exacerbated. We shall show that the regulator can induce effort from the companies to improve their cost efficiency and attain true information revelation of the firms if he accepts the fact that his information on the firms' costs is limited. In other words, society will be better off if the regulator implements a regulatory regime that we call "incentive regulation" than what can be attained under cost-based pricing.

In the second part of the paper, we discuss the regulatory design for network interconnection (call termination), when the companies' effort to improve efficiency as well as the efficiency level of their termination service, c_i^T, constitute the firms' private information. We would obtain similar results if we assumed that the regulator obtains information about the firms' true termination costs with some probability, while it has positive probability that the firms' cost information is "noisy". That is, a company's true cost of call termination may be $\underline{c^T}$, but the regulator may also obtain cost information of $\overline{c^T} = \underline{c^T} + \omega$, where ω denotes the term of random error with a given probability distribution. Note that cost-based pricing assumes that firms' termination cost is either $\underline{c^T}$ or $\overline{c^T}$, each with probability 1. The regulator and the regulated firms play a static game in our model. Companies can improve their cost efficiency by additional effort costs.[8] The regulator has the right to offer a contract

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[8] A thorough analysis of moral hazard followed by adverse selection can be found in *Laffont–Martimort* [2002] pp. 269–294.

menu to the firms.[9] This "regulation game" has a unique Nash equilibrium in each case presented below. The firms themselves play another pricing game within the regulation game that also has a unique equilibrium, as will be shown below.

We assume that two companies offer telecommunications services in the market. Each firm's efficiency level of call termination may have two different values: it may be "high," $\underline{c_i^T}$, or "low," $\overline{c_i^T}$, where the lower bar and the upper bar indicate low marginal cost (high efficiency) and high marginal cost (low efficiency), respectively. It follows from the definition of efficiency that $\underline{c_i^T} < \overline{c_i^T}$ $i = 1, 2$. The distance between firm i's two efficiency levels is $\Delta c_i^T = \overline{c_i^T} - \underline{c_i^T}$.

The regulator does not know the true value of c_i^T, but he knows from past experience that the firms' efficiency may be high or low. The firms can improve their efficiency level with effort. Assuming that the firms' effort (e) can be "high" or "low," $e \in \{e^h, e^\ell\}$,[10] we denote the firm's effort costs $\psi(e)$ as $\psi(e^h) = \psi$, and $\psi(e^\ell) = 0$, respectively.

The regulator can observe the volume (and quality) of service by each firm, but he has only probabilistic knowledge about the companies' effort and efficiency level. These conditional probabilities are based on past experience. The conditional probability of high efficiency if the firm exerted a high effort is given as

$$\nu^h = P(i = h | e^h) = \frac{P(h \cap e^h)}{P(e^h)} .$$

The probability of low efficiency with high effort then becomes $1 - \nu^h$. Similarly, the conditional probability of high efficiency with low effort is ν^ℓ, hence the conditional probability of low efficiency with low effort becomes $1 - \nu^\ell$). We assume that the company is always capable of improving its efficiency level by exerting effort. However, the actual realisation of the efficiency level is a stochastic variable. When the company decides on effort – it may, for instance, invest in an efficiency enhancing technology – it cannot be certain that the effort will reap the expected efficiency level. We assume that the conditional probability of high efficiency is strictly increasing with effort: $\nu^h > \nu^\ell$. The difference between the conditional probabilities of high efficiency with respect to high and low effort is $\Delta\nu^h - \nu^\ell$. We also assume that high effort is always socially optimal, i.e.

$$\Delta\nu(\Delta W^h - W^\ell) \geq \psi, \tag{20}$$

where W^h and W^ℓ are the total economic surpluses from interconnection (inter-firm call termination) with the firms' high and low effort, respectively. Before elaborating the model of incentive regulation, we briefly present the regulatory contract with perfect regulatory information as a benchmark case.

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[9] It could be the other way around: the firms may design and offer the contract menu and the regulator may accept or reject their offer.

[10] We could have assumed a continuous level of effort as we could have had a continuum of types, but it would have rendered the analysis technically more complex without adding to the important results. (See, for instance, *Laffont–Martimort* [2002] pp. 185–186.

We assume that the firms are *risk neutral*, but they are protected by *limited liability*. Under such assumptions, it is not in the firms' interest to reveal their true type and exert high effort. Nevertheless, firms may be induced to reveal their type and exert high effort by the creation of an "information rent," which is allocated by the regulator between the regulated firms. Such an information rent can be financed from a "service provision fund." Firms may pay to or receive payment from this fund. If firm i receives a transfer payment τ per customer in addition to the termination fee it obtains from the other service provider for terminating inter-firm calls, then the firm's net utility per customer becomes

$$u_i(\tau_i, a_i) = \tau_i - \left(c_i^T - a_i\right)\hat{d}_j. \tag{21}$$

The schedule of contracting between the firm and the regulator is as follows:

1. "Nature" sets the probability distributions of the efficiency types conditional on effort. The regulator and the firms learn these probability distributions.
2. The regulator offers a contract menu $\left\{\left(\underline{\tau_i}, \underline{a_i}, \underline{\hat{d}_j}\right), \left(\overline{\tau_i}, \overline{a_i}, \overline{\hat{d}_j}\right)\right\}$ for each combination of effort level and efficiency type for each firm i ($i = 1, 2$). The lower and upper bar variables stand for efficient outcomes and inefficient outcomes, respectively.
3. The firm decides on its effort level without revealing the decision, which thus remains private information.
4. Having selected an effort level, its efficiency type is set as a stochastic function of the firm's effort. (Note that even the firm is unable to know its efficiency type for certain.)
5. The firm delivers the interconnection (call termination) service, customers pay the termination charge as a fraction of the inter-firm calling price, and firms settle the net balance of mutual interconnection charges among themselves according to the rule that has been specified by the regulator.

Additional contracting conditions are set for a firm by its participation constraint, limited liability constraints, and the adverse selection and moral hazard incentive constraints. We assume that the reservation utility of the firms, $\underline{u_i^0}\left(\underline{\tau_i}, \underline{a_i}\right), \overline{u_i^0}(\overline{\tau_i}, \overline{a_i})$, equals zero for all efficiency types. The constraints are introduced below.

Participation constraint • Since the regulator intends to induce high effort by the firm by assumption, the participation constraint is associated only with high effort. It is

$$\nu^h \underline{u_i} + \left(1 - \nu^h\right)\overline{u_i} \geq 0\,.^{11} \tag{22}$$

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[11] Note that u does not have a superscript index. We assume that the regulator prefers high to low effort; consequently, participation must be ensured only for firms exerting high effort. When the superscript index is omitted, the variable or probability always refers to high effort.

Limited liability constraints ◆ We assume that the firm does not possess disposable assets to finance any loss. This is not as strong an assumption as it appears to be. We could allow a loss, say *L,* which would affect our equations with a constant term, but it would not have any substantial effect on the model. The limited liability constraint of the firm with high efficiency is

$$\underline{u_i} \geq 0, \tag{23a}$$

and the limited liability constraint of the firm with low efficiency is

$$\overline{u_i} \geq 0. \tag{23b}$$

Adverse selection incentive compatibility constraints ◆ These constraints ensure that the firm does not mimic another type of efficiency, which is different from its true type, because its utility cannot be higher with lying than with revealing the truth (its true efficiency level). (One may call these "Do not lie!" constraints.) The incentive constraints of the highly efficient firm are

$$\underline{u_i} \geq \overline{u_i} + \Delta c_i^T \overline{\hat{d}_j}, \tag{24a}$$

while the incentive constraints for the firm with low efficiency become

$$\overline{u_i} \geq \underline{u_i} - \Delta c_i^T \underline{\hat{d}_j}, \tag{24b}$$

where $\Delta c_i^T = \overline{c_i^T} - \underline{c_i^T}$, $i = 1, 2$ denotes the difference between high and low marginal costs of call termination.

Moral hazard incentive compatibility constraint ◆ The moral hazard incentive constraint induces the firm to exert high effort provided that high effort is desirable for society. (One may call these "Do not cheat!" constraints.) In other words, the moral hazard incentive constraint ensures that the expected utility of the firm cannot be lower with high than with low effort. The incentive constraint is

$$\nu^h \underline{u_i} + (1 - \nu^h)\overline{u_i} - \psi \geq \nu^\ell \underline{u_i} + (1 - \nu^\ell)\overline{u_i} \Rightarrow \Delta\nu \left(\underline{u_i} - \overline{u_i}\right) \geq \psi. \tag{25}$$

The regulator's objective function ◆ Since the regulator does not possess perfect information about the firms, he must give up some of his benefits in order to induce effort and true revelation. The regulator's lost benefit becomes the firm's information rent. The information rent has two parts. The first part is the firm's limited liability rent, for the firms must be able to charge a higher interconnection fee than what the regulator would otherwise accept because of the firms' limited liability constraint. The second part is the "adverse selection" rent, which acts to induce true revelation of the firms' efficiency type. The regulator's objective function becomes

$$E(W) = \nu^h \left(\underline{W} - \underline{u_1} - \underline{u_2}\right) + (1 - \nu^h)\left(\overline{W} - \overline{u_1} - \overline{u_2}\right) \tag{26}$$

with constraints (22)–(25), where *W* is the social welfare function as given by equation (15).

The relevant constraints ⬩The analysis of constraints reveals that we need to deal only with the limited liability constraints of the less efficient firm (23*b*), the adverse selection constraints of the efficient firm (24*a*), the moral hazard constraint (25), and the following *monotonicity constraint* (derived from the adverse selection constraints):

$$\underline{\hat{d}_j} \geq \overline{\hat{d}_j}\,. \tag{27}$$

The wider the gap between the regulated interconnection fee a_i, $i = 1, 2$, and its first best optimum, the larger the lost economic surplus will be. Consequently, the information rent of the inefficient type must be kept at minimum by the regulator. It then follows from the limited liability constraint of the inefficient firm that

$$\overline{u_i} = 0 \text{ must hold.} \tag{28}$$

The information rent of the efficient type will be affected by the relative strength of the effect of adverse selection and moral hazard. Different constraints may be binding depending on the probability distribution of efficiency types and effort level, and on the magnitude of the effort cost. The regulator faces a trade-off between the information rent, resulting from the adverse selection and limited liability constraints, and the allocative efficiency of the firm with different efficiency types. In certain cases, it makes sense for the regulator to distort the output level of the firm downwards (i.e., away from the first best level of output) in order to save a portion compensation for the information rent of the more efficient type. We show that the downward distortion of output becomes smaller and smaller as the problem of moral hazard is exacerbated.

OPTIMAL CONTRACT MENUS WITH DIFFERENT BINDING CONSTRAINTS

We need to discuss three different cases that are distinguished by the relative magnitude of the information rent and the effort cost. Notably, it will depend on the relative magnitude of the information rent and effort cost which constraints of the different efficiency types will be binding. We only present the first case in detail, when the information rent exceeds the effort cost. Then we outline only the final results of the other two cases, for the technical analysis goes along the same lines in all cases.

Case (a) ⬩ It is assumed that the information rent that a firm can extract with high efficiency is not less than the cost of inducing effort, that is, comparing (24*a*) and (25) we obtain

$$\Delta c_i^T \overline{\hat{d}_j^{SB}} \geq \frac{\psi}{\Delta \nu}, \tag{29}$$

where the second best outcome of interconnection services is denoted by $\hat{d}_i^{SB}$.

The following result is obtained from (29):
If the cost of inducing effort of the efficient firm is smaller than the firm's information rent, then the adverse selection incentive constraint of the efficient firm (24*a*) *is binding:*

$$\underline{u_i} = \Delta c_i^T \overline{\hat{d}_j}. \tag{30}$$

The first order conditions of the regulator's welfare maximisation problem yield optimal charges of call termination with different efficiency types. Substituting (28) and (30) into the regulator's objective function in (26) we get

$$E(W) = \nu^h \left(\underline{W} - \Delta c_1^T \overline{\hat{d}_2} - \Delta c_2^T \overline{\hat{d}_1}\right) + \left(1 - \nu^h\right)\left(\overline{W}\right). \tag{31}$$

The first order conditions of call termination charges yield

$$\begin{gathered} \frac{\partial E(W)}{\partial \underline{a_i}} = \nu^h \left(\underline{a_i} - \underline{c_i^T}\right) \frac{\partial \underline{\hat{d}_j}}{\partial \underline{a_i}} = 0 \\ \frac{\partial E(W)}{\partial \overline{a_i}} = \nu^h \Delta c_i^T \frac{\partial \overline{\hat{d}_j}}{\partial \overline{a_i}} + \left(1 - \nu^h\right)\left(\overline{a_i} - \overline{c_i^T}\right) \frac{\partial \overline{\hat{d}_j}}{\partial \overline{a_i}} = 0, \end{gathered} \tag{32}$$

which sets the following termination fees:

$$\underline{a_i} = \underline{c_i^T} \text{ and } \overline{a_i} = \overline{c_i^T} + \frac{\nu^h}{1 - \nu^h} \Delta c_i^T. \tag{33}$$

Our conclusion is that the different information rents that must be paid to high and to low types, respectively, differ to the extent that is sufficiently large to induce the high effort of all firms. In such cases, the optimal contract menu looks the same as the contract that the regulator would offer in case of pure adverse selection.

Case (b) • It is assumed that the cost of inducing effort is higher than the information rent of the efficient type, but is lower than this information rent would be if the output of the less efficient firm were not reduced below its first best level, i.e.,

$$\Delta c_i^T \overline{\hat{d}_j^{SB}} < \frac{\psi}{\Delta \nu} \leq \Delta c_i^T \overline{\hat{d}_j^{FB}}, \tag{34}$$

where $\overline{\hat{d}_j^{FB}}$ is the first best level of optimum output.

The adverse selection incentive constraint (24*a*) *and the moral hazard incentive constraint* (25) *will equally bind in case of the high efficient firm:*
$\underline{u_i} = \Delta c_i^T \overline{\hat{d}_j}$ *as in* (30) *and*

$$\underline{u_i} = \frac{\psi}{\Delta \nu}, \tag{35}$$

so that equation (35) can be re-written as

$$\Delta \nu \Delta c_i^T \overline{\hat{d}_j} - \psi = 0, \tag{36}$$

and the regulator's objective function becomes

$$E(W) = \nu^h \left(\underline{W} - \Delta c_1^T \overline{\hat{d}_2} - \Delta c_2^T \overline{\hat{d}_1}\right) + \left(1 - \nu^h\right)\left(\overline{W}\right) + \lambda \left(\Delta \nu \Delta c_1^T \overline{\hat{d}_2} - \Delta \nu \Delta c_2^T \overline{\hat{d}_1} - \psi\right). \tag{37}$$

The first order conditions yield

$$\underline{a_i} = \underline{c_i^T} \text{ and } \overline{a_i} = \overline{c_i^T} + \left(\frac{\nu^h}{1-\nu^h}\lambda\Delta\nu\right)\Delta c_j^T \tag{38}$$

where $\lambda > 0$ is the Lagrange multiplier of equation (36).

The results indicate that exacerbated moral hazard results in a larger information rent of the efficient firm in Case (b) than in Case (a). The regulator cannot substantially reduce the information rent by deteriorating allocative efficiency, i.e., by reducing the level of service of the low efficiency type. Consequently, it is sensible to cut back the output of the less efficient firm to a lesser extent. As the first order conditions show, the efficient firm will produce at its first best optimum level. The regulator will distort the output level of the inefficient company downward as in Case (a), but it follows from (38) that this distortion will now be smaller. Consequently, $\overline{a_i}$ is now smaller than in Case (a), and the information rent of the efficient firm under Case (b) will exceed the information rent of the same firm under Case (a). The regulator must pay higher information rent for the gain in allocative efficiency.

Case (c) • It is assumed that the cost of inducing effort is larger than the information rent accrued by the efficient type:

$$\Delta c_i^T \overline{\hat{d}_j^{FB}} < \frac{\psi}{\Delta\nu}. \tag{39}$$

The moral hazard constraint (25) *and the limited liability constraint* (23b) *are binding;*

$$\overline{u_i} = 0 \text{ and } \underline{u_i} = \frac{\psi}{\Delta\nu}.$$

The problem of moral hazard is so pervasive – the cost of inducing effort is so high – that it renders the reduction of the information rent of the more efficient type unfeasible by distorting the output level of the less efficient type downwards. Consequently, each type will produce at its first best level. The regulator's objective function in (26) becomes

$$E(W) = \nu^h\left(\underline{W} - \frac{\psi}{\Delta\nu}\right) + \left(1-\nu^h\right)\underline{W}\,. \tag{40}$$

Solving the first order conditions obtains

$$\underline{a_i} = \underline{c_i^T} \text{ and } \overline{a_i} = \overline{c_i^T}\,. \tag{41}$$

Substituting the results of the three cases into the firm's profit functions in (6), our second proposition is formulated.

PROPOSITION 2 • *Cost-based pricing rewards low efficiency in call termination services in terms of profits, while incentive regulation provides the proper incentives to firms: the companies' higher effort to increase efficiency reaps larger profits.*

Proof • *Efficient types can charge lower, while inefficient types can charge higher termination fees with incentive regulation. But the adverse effect of termination charges will be compensated for the efficient type through the information rent it obtains. The source of this information rent is a direct transfer of revenues from the inefficient to the efficient firm.* ■

As the analysis demonstrates, incentive regulation does not come without a cost. The cost of inducing effort is inversely related to the allocative inefficiency of the firms with different efficiency types in mixed models if moral hazard precedes adverse selection.

DISCUSSION AND CONCLUSIONS

Our most important conclusion is that incentive regulation does not have a perverse effect on the regulated firms' profit and efficiency, while cost-based regulation does have such an effect. Cost-based pricing of call termination ultimately rewards the less efficient types of regulated firms. In contrast, when the regulator offers the regulated firm an incentive-based contract menu, the efficient firm will earn higher profits, while the less efficient firm's profit will be zero. These results suggest that incentive regulation puts an additional burden on the regulator, for he must reallocate a fraction of the termination charge between the less efficient and the most efficient firm. However, this difficulty may not materialise, since firms normally pay each other only the net balance of interconnection charges.

The regulator needs to compare and contrast three possible cases if adverse selection and moral hazard are both present. Regulated firms of both efficiency types provide their service at the first best, Pareto-efficient level in Case (c). The efficient type produces the first best level of output in all other cases as well, but the output level of the less efficient type is downward biased in Cases (a) and (b). In these cases, the regulator is forced to distort allocative efficiency in order to induce information revelation and high effort from any type of regulated firm.

The cost of inducing effort is larger relative to the information rent in Case (b) than in Case (a), and the regulator distorts the output level of the less efficient type downward to a lesser extent in Case (b) than in Case (a). As the cost of inducing effort keeps increasing, as in Cases (b) and (c), the downward distortion of the output level of the less efficient type becomes smaller and smaller. The service levels of firms of different efficiency types come closer and closer to their Pareto-efficient level as the benefit (what the firm can acquire in return for revealing private information) becomes smaller and smaller relative to the effort cost. Consequently, it is less and less necessary and sensible for the regulator to offer an information rent to the firm for information revelation. As the distortion of allocative efficiency becomes smaller, the interconnection charge is also reduced.

Firms are induced to remain inefficient if termination charges are cost-based. In incentive regulation, the regulator transfers a certain amount of information rent from total economic surplus in order to induce effort for efficiency improvement. As a result of true cost revelation, allocative efficiency among firms improves and consumer surplus increases.

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