The design of ownership structure in a vertically related market with unknown upstream costs

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Abstract

We consider a vertically related market characterized by downstream imperfect competition and the monopolistic provision of an essential facility-based input, whose price is set by a regulatory agency. Two possible ownership patterns are examined: the regime of ownership separation, which prevents a single company from having the control of both upstream and downstream operations, and that of legal separation, under which these activities are legally unbundled but common ownership is allowed. We find that with regulatory limited knowledge about the input costs legal separation creates countervailing incentives within the vertical group to use strategically its private information. This allows the regulator to improve social welfare if informational rents are socially costly. When the regulator is interested in maximizing (expected) allocative efficiency only, legal separation still performs better since it implements the competitive outcome through lower transfers to the input monopolist.

Keywords: access charge, legal separation, ownership separation, regulation.

JEL Classification: D82, L11, L51.

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1. Introduction

The large-scale liberalization process that occurred over the last decades has affected many sectors where naturally monopolistic and potentially competitive activities are vertically related. This is especially the case in *network industries*, like the electricity, natural gas, railways and water utilities. The supply of the service to final consumers, which admits competition at least to some extent, requires the use of an essential facility-based input - the network - provided by a monopolistic firm.

A crucial issue in policy debates is how to design the ownership structure before the liberalization process. In practice, this question has received different answers. The Electricity Act of 1989 divided the Central Electricity Generating Board (CEGB) of England and Wales, which operated as a vertically integrated statutory monopoly, in four public limited companies, and transmission grid activities were separated from generation. The same approach was followed in the USA, where, after some important legislative measures, the Order 888 issued by the Federal Energy Regulatory Commission (FERC) in 1996 mandated that owners of regional transmission networks act as common carriers of electric power. Rather than having one vertically integrated provider of electricity, retail customers can now access the wholesale power market directly and purchase unbundled distribution and transmission services from their local utility to deliver power.

On the contrary, in 1984 British Telecommunications (BT) was privatized as a vertically integrated monopoly and only in 1995 there was the accounting separation of its operations into network and retail businesses. Also the privatization of British Gas (BG) in 1986 occurred without restructuring. Even though the government did not follow the 1993 Monopolies and Mergers Commission's recommendation for breaking up the company, now BG supplies its pipeline services through a separate unit.[1]

More recently, the European Union has dealt with the design of ownership structure in network industries. The European directives 2009/72/EC and 2009/73/EC,[2] which concern common rules for the internal market in electricity and natural gas respectively, provide that a transmission system owner, which is part of a vertically integrated undertaking, must be independent *at least* in terms of its legal form, organization and decision-making from other activities not relating to transmission. These rules do *not* create

[1] Newbery (2000) provides a precise account of the most important regulatory reforms of network utilities in the USA and the UK. See also the overview of Viscusi *et al.* (2005), which focuses on the case of the United States.

[2] These directives, issued on 13 July 2009, repeal the directives 2003/54/EC and 2003/55/EC.

an obligation to separate the ownership of assets of the transmission system from the other activities, even though the European Commission had strongly recommended the actual separation of production from network services.

This discussion emphasizes that we can identify two main approaches to the problem of designing the ownership structure in markets where regulated and competitive activities are vertically related. The first one, which prohibits the upstream regulated monopolist from participating (directly or indirectly) in the downstream competitive segment, is known as *ownership* separation. The alternative solution, according to which upstream and downstream operations must be legally unbundled but common ownership is allowed, is usually defined as *legal* separation.

The aim of our paper is to investigate how the ownership structure affects the optimal regulation of the upstream facility.

More precisely, we want to answer the following question. When the regulator determines under asymmetric information the input access price paid by downstream competitive firms, is it better to have *legal separation* or *ownership separation* between upstream and downstream operations?

We consider a vertically related industry in which two firms - one incumbent and one entrant - compete in the downstream market. In reality imperfect competition takes forms which are much more complex. However, we believe that such an assumption is able to capture in a simple way two main aspects that characterize downstream sectors in many network industries. The first feature is the presence of a limited number of firms which can make positive profits.[3] The second element is the existence of a dominant firm (typically the monopolist before liberalization) and one or more rivals which have recently entered the market. Moreover, competition is assumed to be quantity-based, consistently with what occurs in some relevant network industries, like the natural gas market.

We model legal separation by assuming that the downstream incumbent and the upstream monopolist, which provides the essential input, are two different firms with their own separate budgets. This allows the agency to regulate the access price by constraining only the monopoly profits. However, the two firms belong to the same company.[4] In particular, we assume that the downstream firm owns the upstream unit and then it is entitled to receive

[3] Vickers (1995) considers a setting where the number of downstream firms is determined endogenously by free entry, which implies zero profits. He shows that deregulation of the downstream sector may lead to excessive entry and duplication of the fixed costs.

[4] Empirical evidence shows that in most cases the firm which runs the infrastructure segment is actually dominant also in the downstream sector when it is allowed to operate there.

the joint profits.[5]

On the contrary, ownership separation implies a stronger pattern of unbundling since upstream and downstream activities cannot be subject to the same control.

In such a setting, we first consider the benchmark case of complete information and find that both ownership structures bring social welfare to the first-best level. A fully-informed regulator is able to replicate the efficient outcome under both regimes by implementing a different allocation of the total output between the downstream firms through the regulation of access charge.

However, this result no longer holds when the monopolist is privately informed about its marginal costs.[6] Our model predicts that it can be more desirable to implement legal separation. The idea is that within the vertical group the greater upstream profits from exaggerating input costs can be (at least in part) offset by the losses of the downstream branch which pays a higher access price. Consequently, the regime of legal separation yields a *trade-off* between the incentive to overstate the input costs and the incentive to understate. This does not occur under ownership separation, because the monopolist does *not* internalize the impact of its choices on the downstream market. As a consequence, under legal separation the regulator's critical control problem is somehow *relaxed* and it is easier to incentivize the monopolist to reveal its costs as it requires lower (expected) informational rents. When they are socially costly, it turns out that legal separation improves (expected) social welfare. If the regulator is interested in maximizing (expected) allocative efficiency only, this regime can be still preferable since it implements the competitive outcome through lower transfers to the monopolist.

Our analysis suggests that ownership separation should not be *necessarily* thought of as the best solution to mitigate the upstream monopolist's incentive to overstate its costs. This does not imply that legal separation should be preferred in any case. Our results are only meant to be a contribution to the policy debate as they emphasize a beneficial effect of some relevance of legal separation, which creates *countervailing* incentives within the vertical group that can be exploited by the regulator.

[5] The opposite case, in which the upstream firm owns the downstream division, seems to be of less relevance in practice.

[6] See Section 5 for a discussion about the assumption of asymmetric information about upstream costs.

2. Related literature

Lewis and Sappington (1989) already noted that the regulator may gain by creating countervailing incentives for the regulated firm. They illustrate this effect in a model where the firm's technology exhibits fixed costs which are inversely related to marginal costs. In our setting, the design of the ownership structure drives this type of incentives.

Indeed, the topic of this paper is a stimulating issue which has been by and large ignored in the literature. Vickers (1995) had pointed out that ‹‹despite its importance for policy, the question of whether a regulated monopolist should be allowed also to operate in a vertically related industry has received relatively little theoretical attention›› (p. 16). Some years ago Vogelsang (2003) emphasized that asymmetric information between regulators and regulated firms has so far played a minor role in the policy debate for the access pricing in network industries. In their review on optimal regulation, Armstrong and Sappington (2007) have very recently raised the same issue when recognizing that ‹‹further research is warranted on the design of regulatory policy in vertically-integrated industries when regulators are less omniscient›› (p. 1684).

Most economic literature on vertically related markets has actually focused on the choice between ownership separation and vertical integration. It emerges that one of the most important benefits of a policy of ownership separation is the prevention of anticompetitive practices in the unregulated market. When it operates (directly or indirectly) in the retail market, the input monopolist will generally anticipate greater profits from its downstream activities as the costs of its rivals increase. If the regulator is uncertain about the cost for supplying the input, the monopolist will seek to rise the costs of its downstream competitors by exaggerating its input cost. Among others, Vickers (1995) shows analytically that vertical integration can complicate the regulator's critical control problem, since it increases the monopolist's incentives to overstate the access costs.

In this paper we investigate the case of legal separation instead of vertical integration. The main difference is that the former regime allows the agency to regulate the access price by taking into account *only* the monopoly earnings, while the latter requires the regulation of profits of the entire vertical group. This clashes with the liberalization of potentially competitive segments which is a purpose of policy-makers, as is evident from the practical examples quoted above. For instance, in Vickers's (1995) model under vertical integration also the monopolist's profits arising from the downstream competitive activity are constrained by regulatory arrangements. However, as Vickers himself recognizes, regulatory bodies in the UK and elsewhere generally control only the monopolistic activities and allow the firm to operate independently in the deregulated sector, without affecting the outcome of competition there.

Two relevant papers deal with the choice between ownership separation and legal separation and show the superiority of the latter regime on different grounds than the problem of asymmetric information. Cremer *et al.* (2006) study the incentives to invest in the network assets, but they ignore the role of the regulator.

Höffler and Kranz (2007) compare legal unbundling to the outcomes of vertical integration and vertical separation when non-tariff discrimination cannot be prevented. However, the regulator does not suffer from any informational problem when fixing access prices. In their model, under legal unbundling ownership entitles the downstream firm to receive the whole entity's profits, but interferences in the network company's operations are forbidden. Hence, legal unbundling works perfectly in separating the interests of the upstream firm from the rest of the integrated group.[7]

We also suppose that the downstream division maximizes joint profits. However, we relax the assumption of perfect separation of control, which, as Höffler and Kranz (2007) recognize, ‹‹seems often not to be the case›› (p. 25) if we look at the actual practice of legal unbundling. In particular, we assume that upstream monopolist also cares about joint profits. This should better fit the defining characteristic of ownership, which, according to Grossman and Hart (1986), entitles to claim both residual cash-flows (i.e. profits) and residual rights of control. Our framework covers also the case of "accounting separation", a common tool for example in telecom regulation.

The plan of the paper is as follows. Section 3 describes the basic structures of the model. Section 4 shows the outcomes under legal and ownership unbundling in the benchmark case of complete information. In Section 5 we study how the presence of asymmetric information can affect the choice between the two regimes. This enables us to draw some policy recommendations. Section 6 is devoted to some concluding remarks. All relevant calculations and proofs are provided in the appendices.

3. Basic structures of the model

We examine a vertically related industry which supplies a single homogeneous final product. For the sake of convenience, we assume a linear demand

[7] Cremer *et al.* (2006) consider the opposite situation where the downstream firm only maximizes its own profits, while the upstream firm takes also into account the profit of its downstream subsidiary.

function of the form

$$p(Q) = \alpha - \beta Q, \tag{1}$$

where Q denotes total quantity in the downstream market and $\alpha, \beta > 0$ are parameters.

The consumer surplus from purchasing Q units of output is then

$$CS(Q) = \frac{1}{2}\beta Q^2. \tag{2}$$

The upstream regulated monopolist, which provides the access to a crucial input (the network), has a profit equal to

$$\pi_N(Q, a, S) = (a - c^u)Q + S. \tag{3}$$

The network provider receives from the downstream firms a payment a per unit of input. In order to ensure a system a third party access, the monopolist is not allowed to price discriminate between the network users. Moreover, notice from (3) that there is no bypass of the monopolist's access service, so that exactly one unit of upstream input is needed for each unit of the final product.[8] The supply of the upstream service implies a constant marginal cost c^u.[9] The monopolist also obtains a subsidy S via the regulatory process (see below).

We assume that the access price a and the subsidy S are set by a benevolent regulator, which is charged with maximizing the social welfare W, defined as the sum of the consumer surplus CS, the downstream firms' profits π_I and π_E, and the upstream monopolist's profits π_N minus the subsidy S. Formally, we have

$$W \equiv CS + \pi_I + \pi_E + \gamma\pi_N - S, \tag{4}$$

[8] When downstream firms have some ability to substitute away from the monopolist's input, their constant marginal cost $\varphi(a)$ for producing a unit of their own retail service is no longer equal to $a + c$ (where c is the downstream marginal cost), which implies $\varphi''(a) = 0$, but it is a concave function of a, i.e. $\varphi''(a) \leq 0$.

[9] We can imagine that there are also upstream fixed costs which make the activity naturally monopolistic. However, as long as these costs are not excessively large in relation to consumers' valuation of the product, they do not play any role in the analysis and can be ignored.

where $\gamma \in [0,1]$ is a weight on monopoly earnings. If $\gamma \in [0,1)$ the regulator wants to curb monopoly profits since they are financed with public funds. This implies that regulation is aimed at minimizing the subsidization of the network provider.[10] As Armstrong and Sappington (2007) emphasize, this formulation provides similar results to the approach which presumes that subsidies are financed through distortionary taxation. Since a combination between the two approaches introduces additional notation and makes the analysis less transparent without having qualitative effects on results, we assume zero costs of public funds. If $\gamma = 1$ the regulator does not exhibits any distributional concern and maximizes allocative efficiency.[11]

It is important to stress that not only under ownership separation but also under legal separation the regulator controls only the upstream firm, since it represents the legal entity charged with monopoly operations. As pointed out in Section 2, this would be unfeasible under vertical integration, which requires the regulation of profits of the entire vertical group.

The downstream market is characterized by one incumbent firm and one entrant, whose profits are respectively equal to

$$\pi_I (q_I, Q, a) = [p(Q) - c - a] \, q_I \tag{5}$$

and

$$\pi_E (q_E, Q, a) = [p(Q) - c - a] \, q_E, \tag{6}$$

where $Q \equiv q_I + q_E$. Expressions (5) and (6) show that the per-unit profit of each firm is given by the difference between the net revenue from the marketplace $(p - c)$ and the cost a incurred to purchase the access service. The level of downstream marginal costs c is constant and common to both producers. This is clearly a shortcut, since firms may have different costs. In such a case the question of efficient entry would raise, which is of great interest (above all in presence of subsidization) but beyond the scope of this paper. As long as the cost difference is not pronounced,[12] only the allocation of total output between firms would change, while welfare comparisons would be unaffected.[13]

[10] On the other hand, the regulator does not deflate duopoly profits, since downstream activities occur in a liberalized market and cannot be subsidized through public funds.

[11] This corresponds to the case of subsidies financed through lump sum taxes.

[12] This is what we expect when firms sell homogeneous goods.

[13] A high spread between costs may actually make the case of shut-down relevant. However, we intend to examine an environment in which there is competition downstream, and the shut-down is not an issue.

Sometimes the incumbent will be defined as "dominant" firm, because it is supposed to play before the entrant. [14] This assumption captures quite well the main characteristics of markets (like natural gas) in which there is a quantity-based competition between one (big) company already established in the market and one (or more) entrant(s).

We consider two alternative ownership structures. Under ownership separation, the downstream incumbent and the upstream monopolist are fully unbundled and each of them cares only about its own profits.

Under legal unbundling, the two firms are separated only in legal terms. In fact, they constitue a single vertical group, whose aggregate profit from (3) and (5) is given by

$$\pi_V (q_I, q_E, a, S) \equiv \pi_I + \pi_N = [p(Q) - c - c^u] q_I + (a - c^u) q_E + S. \quad (7)$$

This is the sum of the downstream profit, evaluated for access costs equal to the actual upstream costs, and the income that the upstream affiliate receives from the entrant, plus subsidies. Notice that the payment aq_I from the downstream division to the upstream one disappears since it is a mere internal transfer within the vertical group. The downstream division maximizes the profits in (7), since the ownership of the whole entity entitles it to receive joint profits. As discussed in Section 2, we assume that the upstream subsidiary also cares about joint profits, because it internalizes the interests of the vertical group.

4. Complete information

To study in a suitable way the impact of the regulatory knowledge about the input costs on the choice between legal and ownership separation, we first derive the regulatory outcomes under both regimes in the benchmark case of complete information.

Our regulatory model can be represented as a sequential three-stage game. The timing is the following.

(I) The regulator makes a take-it-or-leave-it offer of a regulatory mechanism $\{a, S\}$, which specifies the access charge a and the subsidy S. The upstream monopolist can either accept or reject the offer. If the monopolist refuses the proposed policy (and obtains an outside payoff normalized to zero) the regulatory interaction ends.

(II) In case of acceptance, at the second stage the downstream incumbent determines its production. Under legal separation, the firm takes the whole

[14] See the timing of the regulatory game at the beginning of Section 4.

entity's profits into account, while under ownership separation it maximizes only its own payoff.

(III) Another firm decides whether to enter the market or not and how much to produce.

The game is solved by backward induction. Notice that with ownership unbundling the only difference between the incumbent and the entrant is the asymmetric timing (Stackelberg competition). The idea is that, consistently with practical experience, the former firm remains leader of the market, even though it cannot control the upstream input.

4.1. Legal separation

In the following Proposition we state our main results, which are then discussed in different steps.

Proposition 1 *Under complete information, the regime of legal separation yields*

$$a^{LS} = c^u - \frac{1}{2}(\alpha - c - c^u) \tag{8}$$

$$q_I^{LS} = q_E^{LS} = \frac{1}{2\beta}(\alpha - c - c^u) \tag{9}$$

$$p^{LS} = c + c^u \tag{10}$$

$$\pi_I^{LS} = \pi_E^{LS} = \frac{1}{4\beta}(\alpha - c - c^u)^2 \tag{11}$$

$$S^{LS} = \frac{1}{2\beta}(\alpha - c - c^u)^2 \tag{12}$$

$$W^{LS} = \frac{1}{2\beta}(\alpha - c - c^u)^2, \tag{13}$$

where $\alpha - c - c^u > 0$.[15]

Proof. See Appendix I. ■

The access charge a^{LS} in (8) is set *below* the marginal cost c^u. This means that the regulator finds it optimal to subsidize the input access. Hence, the upstream monopoly receives positive transfers in equilibrium (see (12)). The access pricing policy below costs is designed to offset the potential distortion of the (unregulated) downstream price arising from the presence of imperfect

[15] This is the difference between the consumer maximum willingness to pay α and the total marginal costs $(c + c^u)$.

competition.[16] In fact, as the access charge does not depend on γ (and then it holds also for $\gamma = 1$), this is the value which maximizes allocative efficiency (see also (10)).[17]

The two downstream firms produce the same quantity in equilibrium (see (9)). The subsidization of the access charge definitely benefits the entrant, which can increase its production and offset its strategic disadvantage with respect to the rival. The quantity supplied by the incumbent is determined at the second stage of the regulatory game and then does *not* depend on the access charge a (see (43) in Appendix I). To understand the rationale for this result, we disentangle the overall impact of the access charge on the incumbent's maximization problem in (7). The input price has a direct effect as the downstream branch pays the upstream one an amount equal to aq_I (see (3)). This is a mere internal transfer for the entire group, and not surprinsingly it does not affect joint profits. Moreover, we identify two indirect effects of a, since the quantity of the entrant depends on the access charge and then influences the profits of the vertical group (see (41) in Appendix I). It turns out that also these two effects cancel out and then do not affect the incumbent's optimal decision. The positive impact of a on the marginal downstream profits $\frac{\partial^2 \pi_I}{\partial q_I \partial a}$ through a raise in the final price (as the entrant's quantity decreases) perfectly offsets the negative impact of a on the marginal upstream profits $\frac{\partial^2 \pi_N}{\partial q_I \partial a}$ arising from the lower payment made by the entrant.[18]

[16] This access pricing policy can be implemented as long as transfers to the monopolist are feasible. Armstrong and Sappington (2006) warn against the use of this sort of subsidies in the long-run, because they introduce at least two important problems. Firstly, subsidized access to infrastructure can distort the technological choices of the competitor if the latter decides to use the existing network even though it would employ fewer social resources by building and running its own network. This issue refers to the provision to the entrant of the right *make-or-buy* incentives. Secondly, subsidies may permit an inefficient firm to operate profitably in the market, thereby increasing industry costs and reducing social welfare. However, neither the possibly inefficient bypass nor the threat of inefficient entry are considered in our model.

[17] Notice that the access charge in (8) is *not* efficient in the sense that it ensures the entrant will operate if and only if it is the least-cost industry supplier. Indeed, following the *efficient component pricing rule* (ECPR) - of which Armstrong *et al.* (1996) provide a synthesis - the access price which prevents inefficient entry in our setting is $a^{LS}_{ECPR} = c^u > a^{LS}$, i.e. the sum between the direct cost c^u of proving access and its opportunity cost, which is the lost profit the incumbent incurs when forgoing a unit of business to the entrant (equal to zero since $p - (c + c^u) = 0$ from (10)).

[18] It can be shown from the first-order condition for (42) in Appendix I that $\frac{\partial^2 \pi_I}{\partial q_I \partial a} = -\frac{\partial^2 \pi_N}{\partial q_I \partial a} = \frac{1}{2}$. We should expect in general that these two effects go in opposite directions, even though their exact compensation in our model is driven by the assumptions of Stackelberg competition and linear demand.

Expression (10) shows that the marginal cost pricing is implemented in equilibrium, since price equals total marginal costs. Even if it cannot intervene directly in the liberalized downstream sector, the regulator charges an input price below costs which eliminates any allocative inefficiency arising from imperfect competition.

The two downstream firms earn the same profit in equilibrium (see (11)). This is a straightforward consequence of the even division of the market between them. Moreover, notice that the profit of the incumbent is just the profit of the vertical group ($\pi_I^{LS} = \pi_V^{LS}$), since regulated monopoly operations are unprofitable (see Appendix I).

The marginal cost pricing in (10) implies that legal separation brings social welfare in (13) to the *first-best* level, independently of the regulatory weight on monopoly profits.

4.2. Ownership separation

Following the same procedure as in the previous analysis, we list the main results, which are then investigated into details.

Proposition 2 *Under complete information, the regime of ownership separation yields*

$$a^{OS} = c^u - \frac{1}{3}(\alpha - c - c^u) > a^{OS} \tag{14}$$

$$q_I^{OS} = \frac{2}{3\beta}(\alpha - c - c^u) > q_I^{LS} \tag{15}$$

$$q_E^{OS} = \frac{1}{3\beta}(\alpha - c - c^u) < q_E^{LS} \tag{16}$$

$$p^{OS} = c + c^u = p^{LS} \tag{17}$$

$$\pi_I^{OS} = \frac{2}{9\beta}(\alpha - c - c^u)^2 < \pi_I^{LS} \tag{18}$$

$$\pi_E^{OS} = \frac{1}{9\beta}(\alpha - c - c^u)^2 < \pi_E^{LS} \tag{19}$$

$$S^{OS} = \frac{1}{3\beta}(\alpha - c - c^u)^2 < S^{LS} \tag{20}$$

$$W^{OS} = \frac{1}{2\beta}(\alpha - c - c^u)^2 = W^{LS}. \tag{21}$$

Proof. See Appendix II. ■

Expression (14) shows that even under ownership unbundling the input price is set *below* the marginal costs in equilibrium. A comparison between (8) and (14) reveals that the price distortion below marginal costs is higher under legal separation. Notice that (14) does not depend on γ, so even under ownership separation allocative efficiency is maximized. To achieve this purpose, the regulator finds it optimal to set a lower access charge when the downstream imperfect competition is further undermined by the (indirect) participation of the monopolist in the retail market. While under ownership separation the regulated input price influences the outputs of both firms (see (51) and (52) in Appendix II), under legal separation the regulator can affect only the quantity produced by the entrant (see the discussion in Section 4.1) and then the access price distortion required to achieve allocative efficiency is more pronounced.

Under ownership unbundling the dominant firm produces more than the entrant in the downstream sector (compare (15) and (16)), since now both firms benefit from access subsidization and the incumbent can fully exploit the first move advantage. In equilibrium the independent incumbent supplies a higher quantity than with legal separation, while the entrant proportionally reduces its sales.

Expression (17) shows that the competitive outcome is implemented under both regimes. This means that the total production is unchanged and ownership pattern only affects the allocation of the output between the two firms in equilibrium. Then, we find that under complete information the regimes of legal separation and ownership separation yield the same consumer surplus.

Consistently with the results in (15) and (16), ownership separation allows the incumbent to earn more than the entrant (compare (18) and (19)), even if both firms bear a reduction in their profits relative to the case of legal unbundling. The rationale is that now the higher input cost erodes the firms' profit margin, while the final price is unchanged.

From (21) we immediately derive the following result.

Lemma 1 *Under complete information, the regimes of legal separation and ownership separation bring social welfare to the first-best level.*

Lemma 1 indicates that a fully-informed regulator is able to replicate the efficient outcome under both regimes by implementing a different allocation of the total output between the downstream firms through the regulation of access charge.

Using (20) and (21), we find another result of some interest, which is summarized in the following Lemma.

Lemma 2 *Under complete information, the regime of ownership separation implements the competitive outcome through lower transfers to the input monopolist.*

In order to achieve the first-best, the monopolist must sell below costs under both regimes. Lemma 2 emphasizes that the concern for firm's subsidization is less severe under ownership separation, since the regulator can charge a higher access price.

As we will see, these conclusions no longer hold when the monopolist can use strategically its private information about the input costs.

5. The case of asymmetric information

The results in the previous section have been derived under the condition that the regulator is fully informed. However, as is unanimously recognized in the literature, using Baron and Myerson's (1982) words we can state that ‹‹this assumption is unlikely to be met in reality, since the firm would be expected to have better information about costs than would the regulator›› (p. 911).

We suppose now that the monopolist is privately informed about the upstream marginal costs c^u. Even though regulators may have many instruments at hand to collect information about the regulated part of the industry, this information usually remains imperfect. Sometimes this problem can be even more severe in the unregulated part of the industry. This conclusion can be definitely applied to some contexts like the Lewis and Sappington (1999) model,[19] where the incumbent and the rival firm sell *differentiated* products and then they are likely to exhibit different and possibly uncorrelated costs. On the contrary, in our setup the downstream market provides *homogeneous* goods, whose costs are correlated between firms. In such a case, the regulator can extract quite easily their private information. This would be more costly in the upstream sector, where in the presence of a natural monopoly the firm is disciplined by comparing its activities to those of the monopolists operating in other different environments, which can be also outside the regulator's jurisdiction.

The *revelation principle* ensures that, without any loss of generality, the regulator may be restricted to direct incentive compatible policies, which require the firm to report truthfully its cost parameter.[20] Therefore, the

[19] They derive the optimal access tariffs when the regulator is uncertain about the production costs of the firm which has recently entered the market.

[20] For an application of the revelation principle to regulation, see the seminal paper of Baron and Myerson (1982).

regulatory problem can be reduced to the design of a mechanism $M = \left\{a\left(\widehat{c}^u\right), S\left(\widehat{c}^u\right), \widehat{c}^u \in \left[c_-^u, c_+^u\right]\right\}$, which determines the access charge $a\left(.\right)$ and the subsidy $S\left(.\right)$ to the monopolist as functions of its report $\widehat{c}^u \in \left[c_-^u, c_+^u\right]$, by inducing the firm to reveal honestly its private information, so that in equilibrium $\widehat{c}^u = c^u$. The regulator is supposed to have only imperfect prior knowledge about c^u, represented by a density function $f\left(c^u\right)$, which, to avoid technical problems, is continuous and positive on its domain $\left[c_-^u, c_+^u\right]$. The corresponding cumulative distribution function is given by $F\left(c^u\right) = \int_{c_-^u}^{c^u} f\left(\widehat{c}^u\right) d\widehat{c}^u \in [0, 1]$.

The timing of the regulatory game is the following.

(I) Nature draws a type c^u for the monopolist, according to the density function $f\left(c^u\right)$.

(II) The upstream monopolist learns its type.

(III) The monopolist can either accept or reject the offer of a regulatory mechanism M (see above).

(IV) If the monopolist rejects, the regulatory interaction ends. In case of acceptance, the downstream incumbent determines its production.

(V) The entrant decides whether to enter or not and how much to produce.

5.1. Legal separation

Economic literature has long ago emphasized that a regulated firm has a natural incentive to overstate its costs if the regulator ignores asymmetric information and implements the regulatory policy discussed in Section 4. This conclusion can be definitely applied to the upstream operations. However, as shown in Appendix III, downstream activities benefit from an *understatement* of the upstream costs, since a declared lower value for c^u reduces the access charge and thus increases the profit margin of the downstream branch.

It is evident that the vertical group faces a *trade-off* when it lies. Exaggerating the input costs will be desirable when the extra profit in the upstream market more than offsets the losses on the downstream operations.

This discussion leads to the following result.

Proposition 3 *Under legal separation, the privately-informed upstream division finds it profitable to overstate the costs c^u, i.e. to declare $\widehat{c}^u > c^u$, if and only if*

$$\widehat{c}^u < c_*^u\left(c^u\right), \qquad (22)$$

where $c_*^u\left(c^u\right) \equiv \min\left\{\frac{2}{3}\left(\alpha - c\right) + \frac{1}{3}c^u, c_+^u\right\}$.[21]

[21] The firm's declaration $\widehat{c}^u$ cannot be outside the interval $\left[c_-^u, c_+^u\right]$.

Proof. See Appendix III. ■

As the monopolist cares about joint profits, condition (22) in Proposition 3 shows that it will *not* report a value for $\widehat{c}^u$ higher than the threshold $c^u_*(c^u)$, otherwise the vertical group would be worse off for this statement. The idea is that when the declared cost is sufficiently high the total quantity $Q(\widehat{c}^u) = \frac{\alpha - c - \widehat{c}^u}{\beta}$ (see (9)) is so distorted downwards that the benefit for the upstream branch is more than offset by the loss incurred downstream.[22]

It is important to stress that the vertical group does *not* have any incentive to declare lower costs (see Appendix III for details). The intuition is that the downstream benefit of understating costs, which depends on the quantity produced by the incumbent, is more than compensated by the upstream loss proportional to total overproduction.

For the sake of convenience, we suppose that $c^u_*(c^u) = c^u_+$ if and only if $c^u = c^u_+$, which implies that $\alpha - c - c^u_+ = 0$.[23] In other terms, the highest-cost firm is so inefficient that production cannot occur. Moreover, notice that for $c^u \in [c^u_-, c^u_+)$ we have $c^u_*(c^u) \equiv \frac{2}{3}(\alpha - c) + \frac{1}{3}c^u > c^u$ as $\alpha - c - c^u > 0$.

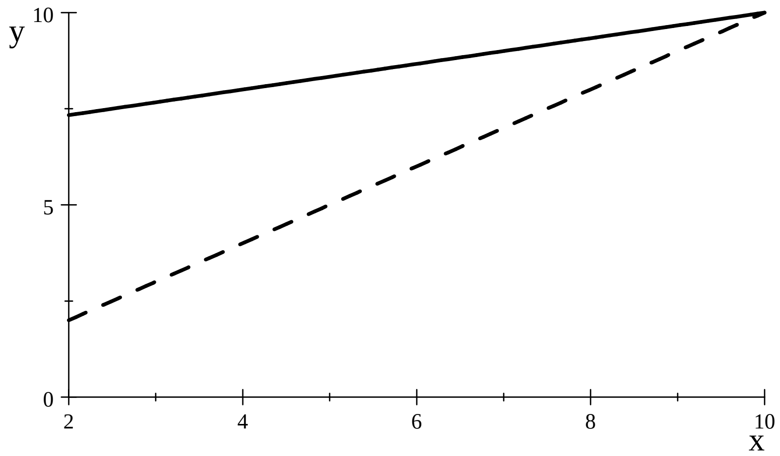

Figure. Incentives to misreport costs under legal separation

The Figure above illustrates graphically this situation.[24] On the x-axis we have the actual upstream costs c^u, while the declared costs $\widehat{c}^u$ are on

[22] Notice that the downstream division produces according to the cost declaration (i.e. $q^{LS}_I(\widehat{c}^u) = \frac{\alpha - c - \widehat{c}^u}{2\beta}$), which can be inferred from the access charge. This is consistent with the very definition of legal separation which prevents the exchange of information between legally separated entities, so that the downstream division should not know the real cost.

[23] Such an assumption entails that there is not a *continuum* of the firm's types that are willing to declare c^u_+. This shortcut guarantees the differentiability of $c^u_*(c^u)$ on the domain $[c^u_-, c^u_+]$.

[24] The lines in the graph are depicted by assuming $\alpha - c = 10$, $c^u_- = 2$, $c^u_+ = 10$.

the y-axis. The area above the bisecting (broken) line represents the case of firm's overstatement of its costs, i.e. $\widehat{c}^u > c^u$. The part of the graph under the other (solid) line captures condition (22), i.e. $\widehat{c}^u < c^u_* (c^u)$.

Any type of the firm with $c^u < c^u_+$ is willing to report a cost parameter $\widehat{c}^u \in (c^u, c^u_* (c^u))$ which is strictly lower than c^u_+. This observation has crucial implications for the following analysis.

We are now in a position to state our main results, which are emphasized in the following Proposition.

Proposition 4 *Under asymmetric information, the regime of legal separation yields*

$$\overline{a}^{LS} = c^u - \frac{1}{2}(\alpha - c - c^u) + \frac{16}{9}(1-\gamma) H(c^u) \tag{23}$$

$$\overline{q}_E^{LS} = \frac{1}{2\beta}\left[\alpha - c - c^u - \frac{16}{9}(1-\gamma) H(c^u)\right] \tag{24}$$

$$\overline{p}^{LS} = c + c^u + \frac{8}{9}(1-\gamma) H(c^u) \tag{25}$$

$$\overline{\pi}_I^{LS} = \frac{1}{4\beta}(\alpha - c - c^u)\left[\alpha - c - c^u - \frac{16}{9}(1-\gamma) H(c^u)\right] \tag{26}$$

$$\overline{\pi}_E^{LS} = \frac{1}{4\beta}\left[\alpha - c - c^u - \frac{16}{9}(1-\gamma) H(c^u)\right]^2 \tag{27}$$

$$\overline{\pi}_N^{LS} = \int_{c^u}^{c^u_*(c^u)} \frac{1}{\beta}\left[\alpha - c - \widetilde{c}^u - \frac{8}{9}(1-\gamma) H(\widetilde{c}^u)\right] d\widetilde{c}^u \tag{28}$$

$$\begin{aligned}\overline{S}^{LS} &= \int_{c^u}^{c^u_*(c^u)} \frac{1}{\beta}\left[\alpha - c - \widetilde{c}^u - \frac{8}{9}(1-\gamma) H(\widetilde{c}^u)\right] d\widetilde{c}^u \\ &+\frac{1}{2\beta}\left[\alpha - c - c^u - \frac{8}{9}(1-\gamma) H(c^u)\right]\left[\alpha - c - c^u - \frac{32}{9}(1-\gamma) H(c^u)\right]\end{aligned} \tag{29}$$

$$\begin{aligned}\overline{W}^{LS} &= \frac{1}{2\beta}\left[(\alpha - c - c^u)^2 - \frac{64}{81}(1-\gamma)^2 H^2(c^u)\right] \\ &- (1-\gamma)\int_{c^u}^{c^u_*(c^u)} \frac{1}{\beta}\left[\alpha - c - \widetilde{c}^u - \frac{8}{9}(1-\gamma) H(\widetilde{c}^u)\right] d\widetilde{c}^u,\end{aligned} \tag{30}$$

where $H(c^u) \equiv \frac{F(c^u)}{f(c^u)} \geq 0$ *is the hazard rate.*[25]

[25] The hazard rate $H(c^u)$ is supposed to be increasing in c^u. This monotonicity property, which is met by the most usual distributions, may be interpreted as a decrease in the conditional probability that there are further cost reductions, given that there has already been a cost marginal reduction, as the firm becomes more efficient.

Proof. See Appendix IV. ■

The optimal mechanism exhibits the usual distorsions arising from asymmetric information. From (23) and (8) we find that if $\gamma \in [0,1)$ the input price is set above its complete-information level. As is evident from (28), this allows the regulator to reduce the monopolist's informational rents (which ensure incentive compatibility) when they are socially costly. Hence, in principle we cannot predict whether the input will be subsidized in equilibrium or not. In fact, the sign of (29) depends on the realized c^u.

The quantity supplied by the incumbent is the same as that with complete information in (9), since it does not depend on the access charge and thus cannot be distorted by the regulator in equilibrium. As (24) is lower than (9), the higher asymmetric-information access charge yields a reduction in the quantity produced by the entrant.

A quick look at (25) and (10) shows that if $\gamma \in [0,1)$ the price is distorted above the complete-information level, which makes consumers worse off. This is a direct consequence of the increase in the access charge in (23). The gains from reducing the informational rents in (28) come at the expense of a decrease in consumer surplus, since they imply allocative inefficiency. However, notice that the distortion of the input price translates into a lower raise in the final price. If $\gamma = 1$, the competitive outcome is restored.

As Appendix IV illustrates, expression (26) is lower than (11), which means that the incumbent is worse off because of asymmetric information. We can easily see that the entrant is also penalized by the situation of asymmetric information, since its profit in (27) is lower than that in (11). This is the result of two combined effects. The first one is the reduction in the quantity produced by the entrant seen before. The second factor is the decrease in the profit margin. Indeed, the higher downstream price from which the firm benefits is more than offset by the greater access price that it has to pay. However, the incumbent is relatively less penalized by the situation of asymmetric information than the entrant (see Appendix IV for details). The motivation is that, even if it incurs the same reduction in the profit margin as its competitor, the quantity which it produces is unchanged, as we have already seen.

The downward distortion of the entrant's production in (24) entails a reduction in the total output, captured by the integrand in (28), which allows the regulator to curb the socially costly rent (if $\gamma \in [0,1)$) that the monopolist extracts for its informational advantage.[26]

[26] As shown in Appendix IV.B, expression (28) satisfies the standard property of decreasing monotonocity in c^u. This corresponds to the intuitive notion that the profit should increase in the efficiency of the firm.

It is immediate to see from (30) and (13) that the situation of asymmetric information is social-welfare detrimental, as long as the regulator has some distributional concern. There are two elements of distortion with respect to the complete-information case. The first one, captured by the term in the first square brackets, concerns the reduction in consumer surplus and in downstream profits. The second factor, represented by the integral, refers to the part of the informational rent of the monopolist which constitutes a mere welfare loss. If $\gamma = 1$, legal separation brings social welfare to the first-best level and asymmetric information does not have any impact on allocative efficiency. This corresponds to the well-known Loeb and Magat (1979) result.

5.2. Ownership separation

The following Proposition shows the main results, which are then discussed in different steps.

Proposition 5 *Under asymmetric information, the regime of ownership separation yields*

$$\overline{a}^{OS} = c^u - \frac{1}{3}(\alpha - c - c^u) + \frac{4}{3}(1-\gamma) H(c^u) \tag{31}$$

$$\overline{q}_I^{OS} = \frac{2}{3\beta}\left[\alpha - c - c^u - (1-\gamma) H(c^u)\right] \tag{32}$$

$$\overline{q}_E^{OS} = \frac{1}{3\beta}\left[\alpha - c - c^u - (1-\gamma) H(c^u)\right] \tag{33}$$

$$\overline{p}^{OS} = c + c^u + (1-\gamma) H(c^u) \tag{34}$$

$$\overline{\pi}_I^{OS} = \frac{2}{9\beta}\left[\alpha - c - c^u - (1-\gamma) H(c^u)\right]^2 \tag{35}$$

$$\overline{\pi}_E^{OS} = \frac{1}{9\beta}\left[\alpha - c - c^u - (1-\gamma) H(c^u)\right]^2 \tag{36}$$

$$\overline{\pi}_N^{OS} = \int_{c^u}^{c^u_+} \frac{1}{\beta}\left[\alpha - c - \widetilde{c}^u - (1-\gamma) H(\widetilde{c}^u)\right] d\widetilde{c}^u \tag{37}$$

$$\overline{S}^{OS} = \int_{c^u}^{c^u_+} \frac{1}{\beta}\left[\alpha - c - \widetilde{c}^u - (1-\gamma) H(\widetilde{c}^u)\right] d\widetilde{c}^u$$

$$+\frac{1}{\beta}\left[\alpha - c - c^u - (1-\gamma) H(c^u)\right]\left[\alpha - c - c^u - 4(1-\gamma) H(c^u)\right] \tag{38}$$

$$\overline{W}^{OS} = \frac{1}{2\beta}\left[(\alpha - c - c^u)^2 - (1-\gamma)^2 H^2(c^u)\right]$$
$$-(1-\gamma)\int_{c^u}^{c^u_+}\frac{1}{\beta}\left[\alpha - c - \widetilde{c}^u - (1-\gamma)H(\widetilde{c}^u)\right]d\widetilde{c}^u. \qquad (39)$$

Proof. See Appendix V. ■

The optimal mechanism reflects the standard distortion due to asymmetric information. It appears from (31) and (14) that if $\gamma \in [0,1)$ even under ownership unbundling the equilibrium input price is set above the complete-information level. Notice from (31) and (23) that we cannot know *a priori* whether the access charge will be higher under ownership separation, as with complete information. This is the result of two opposite effects. On the one hand, the regulator applies a lower distortion under ownership separation in response to the asymmetric-information problem $\left(\frac{4}{3}(1-\gamma)H \leq \frac{16}{9}(1-\gamma)H\right)$. On the other hand, we know from (14) that under this regime the complete-information input price is less distorted below marginal cost. We have argued in Section 4.2 that this occurs because the regulator can (indirectly) affect outputs of both downstream firms rather than only that of the entrant. For the same reason the access charge is less distorted due to asymmetric information. Since the two distortions go in opposite directions, we cannot predict whether the regime of ownership separation yields a higher access price even under asymmetric information.

It is immediate to see from (32) and (15) that the higher input price leads to a reduction in the production of the incumbent under asymmetric information. A quick look at (33) and (16) shows that the entrant also will produce less because of the asymmetric-information problem.

As under legal separation, if $\gamma \in [0,1)$ the increase in the access charge in (31) arising from asymmetric information implies a lower distortion in the final price. More relevantly, we see from (34) and (25) that consumers pay a *higher* price under ownership separation ($\overline{p}^{OS} > \overline{p}^{LS}$). The rationale for this result will be analyzed when we derive the upstream informational rents. If $\gamma = 1$, even under ownership separation the efficient outcome is implemented.

As shown in Appendix V, we find from (35) and (18) that the asymmetric information problem hurts the incumbent. Not surprisingly, the entrant also is worse off under asymmetric information (see (36) and (19)). However, the incumbent is more penalized than the entrant by asymmetric information (see Appendix V for details). This is the *opposite* of what we found under legal separation. The rationale is that now both firms incur a reduction in their profit margin and output, so the incumbent will suffer relatively more from the problem of asymmetric information.

As for informational rents, notice that the range between boundaries of the integral in (37) is higher than that in (28), as $c_+^u > c_*^u(c^u)$ for $c^u \in [c_-^u, c_+^u)$. The rationale is that under ownership separation the monopolist with costs c^u has an incentive to report $\widehat{c}^u \in (c^u, c_+^u]$, i.e. to mimic any more inefficient type of the firm, and it has to be accordingly remunerated in order to reveal the truth. Under legal separation, this incentive is *weaker*, since the monopolist does not find it profitable to declare $\widehat{c}^u > c_*^u(c^u)$. If $\gamma \in [0, 1)$ this implies a *higher* distortion of total output under ownership separation in order to curb the monopolist's (socially costly) informational rents, as is evident from the comparison between the integrands (which capture the total production) in (37) and (28). Consequently, consumers will pay higher prices, as we have already noticed.

From (39) and (21) we can see that if $\gamma \in [0, 1)$ the presence of asymmetric information still produces two effects. The first one, which appears in the expression in the first square brackets, concerns the distortion in total output. Not surprisingly, the bracketed term in (39) is lower than that in (21). The second factor, which is captured by the integral, refers to the part of the monopolist's informational rent which is considered as a social loss. If $\gamma = 1$, even ownership separation brings social welfare to the first-best level.

5.3. Welfare comparisons

We start by considering consumer surplus under the two regimes.

Proposition 6 *Under asymmetric information, as long as informational rents are socially costly, i.e.* $\gamma \in [0, 1)$*, the regime of legal separation makes consumers better off. If* $\gamma = 1$*, the two regimes yield the same consumer surplus.*

Proof. Compare (69) and (84) in Appendices IV and V, respectively. ■

The lower price arising under legal separation (see Section 5.2) allows to reach a higher allocative efficiency in the presence of a regulatory concern about monopoly profits.

Subtracting (28) from (37) we get after some manipulations

$$\overline{\pi}_N^{OS} - \overline{\pi}_N^{LS} = \int\limits_{c_*^u(c^u)}^{c_+^u} \frac{1}{\beta} \left[\alpha - c - \widetilde{c}^u - (1-\gamma) H(\widetilde{c}^u)\right] d\widetilde{c}^u - \frac{1-\gamma}{9\beta} \int\limits_{c^u}^{c_*^u(c^u)} H(\widetilde{c}^u)\, d\widetilde{c}^u, \tag{40}$$

whose sign is ambiguous. Notice that (40) is the difference between the *ex post* informational rents distributed only under ownership separation in the interval $\left[c_*^u(c^u), c_+^u\right)$ and the higher rents paid under legal separation in the range $\left[c_-^u, c_*^u(c^u)\right)$. This is the result of the trade-off between the wider interval where it is profitable to lie under ownership separation, which yields *ceteris paribus* higher informational rents, and the greater downward distortion in the total output, which is aimed at reducing these rents.

Comparing the *ex ante* informational rents under the two regimes leads to the following result.

Proposition 7 *Under asymmetric information, the regime of legal separation gives the input monopolist lower expected informational rents.*

Proof. See Appendix VI. ■

Legal unbundling generates a trade-off within the vertical group between the incentive to exaggerate private information in order to have higher upstream profits and the incentive to understate this information in order to pay a lower access charge downstream. Hence, the benefit of overstating input costs can be (at least in part) counterbalanced by the loss incurred downstream. This does *not* occur under ownership separation, since the monopolist neglects the impact of its choices on the downstream market. Hence, legal separation yields *countervailing* incentives which allow the regulator to curb *ex ante* informational rents.

The results in Propositions 6 and 7 drive the following conclusion.

Proposition 8 *Under asymmetric information, as long as informational rents are socially costly, i.e.* $\gamma \in [0, 1)$*, the regime of legal separation yields a higher expected social welfare level.*

Proof. See Appendix VII. ■

Proposition 8 emphasizes that when the regulator has limited knowledge of the industry it can be desirable to separate the input monopolist from the downstream incumbent just in *legal* terms so that they can still belong to the same company. This is the case if the regulator exhibits some concern about the distribution of informational rents to the monopolist, i.e. if $\gamma \in [0, 1)$. The rationale is that legal separation achieves a trade-off between allocative efficiency and rent extraction which is (expected) social welfare improving.

We derive now another result of some interest, which is emphasized in the following Proposition.

Proposition 9 *Under asymmetric information, when the regulator is interested in maximizing (expected) allocative efficiency only, i.e. if* $\gamma = 1$*,* *the regime of legal separation implements the competitive outcome at lower transfers to the input monopolist.*

Proof. Compare (29) and (38) for $\gamma = 1$. ■

Even in absence of any concern about the informational rents, legal separation can be more desirable since it allows to achieve allocative efficiency at lower costs in terms of monopolist's subsidization.

Notice that the result in Proposition 9 is the *opposite* of what we found under complete information (see Lemma 2), where ownership separation implements the first-best at a lower cost in terms of subsidies to make the monopoly viable. Under asymmetric information, on balance legal separation curbs the amount of transfers which allow viability and finance informational rents. Hence, this regime can be preferable since it reduces the monopoly subsidization.

The results in Propositions 8 and 9 have implications of some relevance. Often in the literature and in policy debates the regime of ownership separation between the input monopolist and the downstream incumbent is commonly thought of as the best solution to the regulator's critical control problem, since it should remove the monopolist's practice of exaggerating the input costs in order to worsen the competitiveness of the downstream rivals. However, the monopolist's incentives to exploit its private information continue to play a relevant role. Our model emphasizes a beneficial effect of legal separation, since it creates a *conflict of interests* within the vertical group, which reduces the detrimental effects of asymmetric information.

6. Concluding remarks

In this paper we have dealt with the problem of how to design the ownership structure in a vertically related market when the regulator is charged with setting the price for the access to an upstream monopolistic input and there is imperfect competition downstream. Although the literature on the access pricing is quite extensive, this is an issue that, despite its importance for the liberalization process, has been by and large ignored in the economic research.

Empirical evidence shows that there are two main ownership patterns that have been recently implemented. Under legal separation upstream and downstream operations are legally unbundled but common ownership is permitted. On the contrary, ownership separation prevents a single company from controlling both activities. We have studied the welfare impact of a problem that has so far played a minor role in the policy debate about access pricing: the asymmetric information about industry on the part of the regulator. While under complete information the two ownership regimes can bring social welfare to the first-best level, we have found that regulatory limited knowledge about the monopolist's input costs implies that legal separation can perform better either since it improves (expected) social welfare (when informational rents are costly) or since it allows to achieve the competitive outcome through a lower monopoly subsidization. The idea is that a trade-off occurs within the vertical group between the incentive to overstate its costs in order to get higher upstream profits and incentive to understate them to pay a lower access charge downstream. The policy implication of this result is that owership separation should not be necessarily considered as the best solution to deal with the problem of the monopolist's incentive to raise the input costs. Under legal separation the regulator can exploit the conflict of interests that emerges between the two branches of the vertical group and reduce the detrimental effects of asymmetric information.

We believe that our analysis can be extended in a variety of directions. We would like to mention three suggestions which are left for future research.

First of all, we have considered only two downstream firms, one incumbent and one entrant. However, in the literature imperfect competition is usually modelled by assuming a dominant firm and a competitive fringe which makes zero profits. Would our results change in this case?

Other development would be the study of a more realistic setting where the regulator is uncertain not only about the costs of the upstream monopolist but also those of the downstream firms.

Finally, it would be interesting to investigate in our model the issues of the possible bypass of the infrastructure by entrants and the impact on production efficiency of increased competition.

Appendix I

Applying the backward induction procedure, we start by deriving the entrant's strategy at the last stage. Substituting (1) into (6), we write down the entrant's maximization problem as

$$\max_{q_E} \left(\alpha - \beta q_E - \beta q_I - c - a\right) q_E.$$

The first-order condition for q_E yields the entrant's best reply function

$$q_E\left(q_I, a\right) = \frac{1}{2\beta}\left(\alpha - \beta q_I - c - a\right). \qquad (41)$$

Plugging (41) into (7), the maximization problem of the incumbent at the second stage is

$$\max_{q_I} \left[\alpha - \frac{1}{2} (\alpha - \beta q_I - c - a) - \beta q_I - c - c^u \right] q_I$$

$$+ \frac{1}{2\beta} (a - c^u) (\alpha - \beta q_I - c - a) + S. \tag{42}$$

From (42) the first-order condition for q_I can be written as

$$-\beta q_I + \frac{1}{2} (\alpha - c - c^u) = 0. \tag{43}$$

Solving (43) for q_I yields the downstream output produced by the incumbent, which is given by (9) in Proposition 1 of the paper. If we replace (9) into (41) we obtain

$$q_E (a) = \frac{1}{4\beta} (\alpha - c + c^u - 2a). \tag{44}$$

At the first stage, the regulator determines the access price a and the subsidy S in order to maximize social welfare in (4). Substituting (9) and (44) into (4) yields after some manipulations

$$\max_{a,S} \frac{\beta}{2} \left(\frac{3\alpha - 3c - c^u - 2a}{4\beta} \right)^2 + \left[\alpha - \frac{1}{4} (3\alpha - 3c - c^u - 2a) - c - a \right]$$

$$\cdot \frac{1}{4\beta} (3\alpha - 3c - c^u - 2a) + \gamma \left[\frac{1}{4\beta} (a - c^u) (3\alpha - 3c - c^u - 2a) + S \right] - S \tag{45}$$

$$s.t. \quad (PC_C), (PC_E), (PC_I), (PC_N),$$

where (PC$_C$), (PC$_E$), (PC$_I$) and (PC$_N$) are nonnegative utility constraints which guarantee the participation of the consumers, the entrant, and the downstream and upstream branches of the vertical group, respectively. It is important to stress that both parts of the vertical group are assumed to receive a nonnegative profit, since they are independent in terms of their legal form.[27]

We replace S with π_N, since from (3) there is a bijective correspondence between the two variables for a given a. Ignoring all the participation constraints but (PC_N),[28] the program in (45) becomes

$$\max_{a,\pi_N} \frac{\beta}{2}\left(\frac{3\alpha-3c-c^u-2a}{4\beta}\right)^2+\left[\alpha-\frac{1}{4}\left(3\alpha-3c-c^u-2a\right)-c-a\right]$$

$$\cdot\frac{1}{4\beta}\left(3\alpha-3c-c^u-2a\right)+\left(a-c^u\right)\frac{1}{4\beta}\left(3\alpha-3c-c^u-2a\right)-\left(1-\gamma\right)\pi_N \quad (46)$$

$$s.t. \quad (PC_N).$$

Notice that the objective function in (46) is decreasing in π_N, so $\pi_N^{LS}=0$. The first-order condition for a is given by

$$-\frac{1}{8\beta}\left(3\alpha-3c-c^u-2a\right)-\frac{1}{8\beta}\left(3\alpha-3c-c^u-2a\right)$$

$$-\frac{1}{8\beta}\left(\alpha-c+c^u-2a\right)+\frac{1}{4\beta}\left(3\alpha-3c-c^u-2a\right)-\frac{1}{2\beta}\left(a-c^u\right)=0. \quad (47)$$

From (47) we can now derive the optimal access charge in (8) of Proposition 1. Substituting (8) into (44) yields the quantity supplied by the entrant in (9) of Proposition 1. Plugging (9) into (1) we immediately find that final consumers pay the price given by (10) in Proposition 1. Using (2), consumer surplus amounts to

$$CS^{LS}=\frac{1}{2\beta}\left(\alpha-c-c^u\right)^2. \quad (48)$$

If we replace (9) into (5) and (6) respectively, we get firms' profits in (11) of Proposition 1. Recalling that $\pi_N^{LS}=0$, we can compute from (3) the subsidy received by the monopolist, which is given by (12) in Proposition 1. Using (11), (12) and (48), we can finally derive the complete-information social welfare in (13) of Proposition 1.

[27] Under vertical integration, we would have one single constraint for the entire group, whose profit could not be split between upstream and downstream activities.

[28] It can be easily seen that they are all satisfied in equilibrium.

Appendix II

To solve the regulatory game under ownership separation we adopt again the backward induction procedure. While (41) at the last stage still holds, the second-stage maximization problem of the incumbent in the downstream market must be reformulated, since the leader is now a separate firm which is independent from the upstream monopolist even in terms of ownership. Substituting (41) into (5), the incumbent's maximization program becomes

$$\max_{q_I} \left[\alpha - \frac{1}{2} (\alpha - \beta q_I - c - a) - \beta q_I - c - a \right] q_I. \tag{49}$$

From (49) the first-order condition for q_I is given by

$$-\beta q_I + \frac{1}{2} (\alpha - c - a) = 0. \tag{50}$$

Using (50) we get

$$q_I (a) = \frac{1}{2\beta} (\alpha - c - a). \tag{51}$$

Plugging (51) into (41) yields

$$q_E (a) = \frac{1}{4\beta} (\alpha - c - a). \tag{52}$$

At the first stage, using (51) and (52) the regulator's maximization problem in (4) may be rewritten after some computations as

$$\max_{a,S} \frac{\beta}{2} \left(3 \frac{\alpha - c - a}{4\beta} \right)^2 + \left[\alpha - \frac{3}{4} (\alpha - c - a) - c - a \right]$$

$$\cdot \frac{3}{4\beta} (\alpha - c - a) + \gamma \left[(a - c^u) \frac{3}{4\beta} (\alpha - c - a) + S \right] - S \tag{53}$$

$$s.t. \quad (PC_C),\ (PC_E),\ (PC_I),\ (PC_N).$$

Ignoring all the participation constraints but (PC_N)[29] and replacing from (3) the choice variable S with π_N, the maximization problem in (53) becomes

$$\max_{a,\pi_N} \frac{\beta}{2}\left(3\frac{\alpha-c-a}{4\beta}\right)^2+\left[\alpha-\frac{3}{4}(\alpha-c-a)-c-a\right]\frac{3}{4\beta}(\alpha-c-a)$$

$$+(a-c^u)\frac{3}{4\beta}(\alpha-c-a)-(1-\gamma)\pi_N \quad s.t. \quad (PC_N). \tag{54}$$

Since the objective function in (54) is decreasing in π_N, the regulator finds it optimal to give zero profits to the input monopolist ($\pi_N^{OS}=0$).

The first-order condition for a is given by

$$-\frac{9}{16\beta}(\alpha-c-a)-\frac{3}{16\beta}(\alpha-c-a)-\frac{3}{16\beta}(\alpha-c-a)$$

$$+\frac{3}{4\beta}(\alpha-c-a)-\frac{3}{4\beta}(a-c^u)=0. \tag{55}$$

From (55) we can derive the input price in (14) of Proposition 2 in the paper. Substituting (14) into (51) and (52) yields the quantities supplied by the incumbent and the entrant, which are respectively given by (15) and (16) in Proposition 2. Plugging (15) and (16) into (1) we can compute the downstream market price in (17) of Proposition 2. Using (2), consumer surplus is equal to

$$CS^{OS}=\frac{1}{2\beta}(\alpha-c-c^u)^2. \tag{56}$$

From (5) and (6) we find that the profits of the incumbent and the entrant are respectively equal to (18) and (19) in Proposition 2. Using (3) and recalling that $\pi_N^{OS}=0$ yields the transfer to the monopolist in (20) of Proposition 2. From (18), (19), (20) and (56), we can finally figure out the complete-information social welfare in (21) of Proposition 2.

[29] It can be easily seen that they are all satisfied in equilibrium.

Appendix III

Let us define $\pi_N^{LS}(c^u) \equiv \pi_N^{LS}(c^u, c^u)$ and $\pi_N^{LS}(\widehat{c}^u) \equiv \pi_N^{LS}(\widehat{c}^u, \widehat{c}^u)$ as the monopolist's profit when reporting truthfully its cost c^u or $\widehat{c}^u$. Moreover, $Q^{LS}(\widehat{c}^u) = \frac{\alpha - c - \widehat{c}^u}{\beta} \geq 0$ represents the total output derived from (9) for $c^u = \widehat{c}^u$. The extra profit $\Delta\pi_N^{LS}(\widehat{c}^u, c^u) \equiv \pi_N^{LS}(\widehat{c}^u, c^u) - \pi_N^{LS}(c^u)$ that the monopolist obtains when declaring $\widehat{c}^u$ rather than its true costs c^u is given by

$$\Delta\pi_N^{LS}(\widehat{c}^u, c^u) = [a(\widehat{c}^u) - c^u] Q^{LS}(\widehat{c}^u) + S^{LS}(\widehat{c}^u) - \pi_N^{LS}(c^u)$$

$$= \pi_N^{LS}(\widehat{c}^u) + (\widehat{c}^u - c^u) Q^{LS}(\widehat{c}^u) - \pi_N^{LS}(c^u) = (\widehat{c}^u - c^u) \frac{\alpha - c - \widehat{c}^u}{\beta}, \quad (57)$$

where $\pi_N^{LS}(\widehat{c}^u) = \pi_N^{LS}(c^u) = 0$, since any type of firm which reports the truth gets zero profits when the complete-information regulatory policy is applied. From (57) it turns out that $\Delta\pi_N^{LS}(\widehat{c}^u, c^u) \geq 0$ if $\widehat{c}^u > c^u$.

Let us define now $\pi_I^{LS}(\widehat{c}^u) \equiv [p(Q(\widehat{c}^u)) - c - a(\widehat{c}^u)] q_I^{LS}(\widehat{c}^u)$ as the profit of the downstream division when $\widehat{c}^u$ is reported instead of c^u. Using (11), the difference in profit $\Delta\pi_I^{LS}(\widehat{c}^u, c^u) \equiv \pi_I^{LS}(\widehat{c}^u) - \pi_I^{LS}(c^u)$ is equal to

$$\Delta\pi_I^{LS}(\widehat{c}^u, c^u) = \frac{1}{4\beta}\left[(\alpha - c - \widehat{c}^u)^2 - (\alpha - c - c^u)^2\right]$$

$$= -\frac{1}{4\beta}(\widehat{c}^u - c^u)\left[(\alpha - c - c^u) + (\alpha - c - \widehat{c}^u)\right], \quad (58)$$

where the the bracketed expression in the last line is the sum of two nonnegative terms). It turns out that $\Delta\pi_I^{LS}(\widehat{c}^u, c^u) \geq 0$ if $\widehat{c}^u < c^u$.

Then, declaring $\widehat{c}^u > c^u$ increases joint profits if

$$\Delta\pi_N^{LS}(\widehat{c}^u, c^u) > \left|\Delta\pi_I^{LS}(\widehat{c}^u, c^u)\right|. \quad (59)$$

Substituting (57) and (58) into (59) yields after some manipulations

$$(\widehat{c}^u - c^u)(\alpha - c - \widehat{c}^u) > \frac{1}{3}(\widehat{c}^u - c^u)(\alpha - c - c^u). \quad (60)$$

After dividing both sides of (60) by $\widehat{c}^u - c^u > 0$, we find $\frac{\alpha-c-\widehat{c}^u}{\alpha-c-c^u} > \frac{1}{3}$, which immediately yields (22) in Proposition 3 of the paper.

It is important to stress that the firm does not have any incentive to understate its costs ($\widehat{c}^u < c^u$). The condition for this to be the case $\left|\Delta\pi_N^{LS}\left(\widehat{c}^u, c^u\right)\right| < \Delta\pi_I^{LS}\left(\widehat{c}^u, c^u\right)$ implies $\frac{\alpha-c-\widehat{c}^u}{\alpha-c-c^u} < \frac{1}{3}$, which is never met (since the left-hand side is greater than one for $\widehat{c}^u < c^u$).

Appendix IV

We solve the regulatory game according to the optimal menu. Substituting the outcomes at the last two stages in (9) and (44), which still hold, into the regulator's maximization problem in (4) at the first stage, we get after some manipulations

$$\max_{a(c^u),S(c^u)} \int_{c_-^u}^{c_+^u} \left\{ \frac{\beta}{2}\left[\frac{3\alpha - 3c - c^u - 2a\left(c^u\right)}{4\beta}\right]^2 \right.$$

$$+\left[\alpha - \frac{1}{4}\left(3\alpha - 3c - c^u - 2a\left(c^u\right)\right) - c - a\left(c^u\right)\right]\frac{1}{4\beta}\left(3\alpha - 3c - c^u - 2a\left(c^u\right)\right)$$

$$\left. +\gamma\left[\left(a\left(c^u\right) - c^u\right)\frac{1}{4\beta}\left(3\alpha - 3c - c^u - 2a\left(c^u\right)\right) + S\left(c^u\right)\right] - S\left(c^u\right)\right\} f\left(c^u\right)dc^u \tag{61}$$

$$s.t. \quad (PC_C),\ (PC_E),\ (PC_I),\ (PC_N)$$

and

$$\pi_N\left(c^u, c^u\right) \equiv \pi_N\left(c^u\right) \geq \pi_N\left(\widehat{c}^u, c^u\right), \text{ for any } \widehat{c}^u, c^u \in \left[c_-^u, c_+^u\right].$$

The last condition captures the incentive compatibility constraint of the network provider. Appendix IV.A shows that under legal separation it reduces to

$$\pi_N^{LS}\left(c^u\right) = \pi_N^{LS}\left(c_*^u\left(c^u\right)\right) + \int_{c^u}^{c_*^u(c^u)} \frac{3\alpha - 3c - \widetilde{c}^u - 2a\left(\widetilde{c}^u\right)}{4\beta} d\widetilde{c}^u. \tag{ICC$_N^{LS}$}$$

We can ignore all the participation constraints but (PC_N).[30] Substituting (ICC_N^{LS}) into the objective function in (61) and replacing the choice variable $S(c^u)$ with $\pi_N^{LS}(c_*^u(c^u))$ yields

$$\max_{a(c^u),\pi_N^{LS}(c_*^u(c^u))} \int_{c_-^u}^{c_+^u} \left\{ \frac{\beta}{2}\left[\frac{3\alpha-3c-c^u-2a(c^u)}{4\beta}\right]^2 \right.$$

$$+\left[\alpha-\frac{1}{4}(3\alpha-3c-c^u-2a(c^u))-c-a(c^u)\right]$$

$$\cdot\frac{1}{4\beta}(3\alpha-3c-c^u-2a(c^u))+(a(c^u)-c^u)\frac{1}{4\beta}(3\alpha-3c-c^u-2a(c^u))$$

$$\left. -(1-\gamma)\int_{c^u}^{c_*^u(c^u)}\frac{3\alpha-3c-\widetilde{c}^u-2a(\widetilde{c}^u)}{4\beta}d\widetilde{c}^u-(1-\gamma)\pi_N^{LS}(c_*^u(c^u))\right\} f(c^u)\,dc^u \tag{62}$$

$$s.t. \quad (PC_N).$$

Since the objective function in (62) is decreasing in $\pi_N(c_*^u(c^u))$, the regulator finds it optimal to set $\pi_N^{LS}(c_*^u(c^u))=0$, still satisfying (PC_N) since the integral in (ICC_N^{LS}) is nonnegative.[31]

Integrating by parts yields

$$\int_{c_-^u}^{c_+^u}\int_{c^u}^{c_*^u(c^u)}\frac{3\alpha-3c-\widetilde{c}^u-2a(\widetilde{c}^u)}{4\beta}d\widetilde{c}^u f(c^u)\,dc^u$$

$$=\left[\int_{c^u}^{c_*^u(c^u)}\frac{3\alpha-3c-\widetilde{c}^u-2a(\widetilde{c}^u)}{4\beta}d\widetilde{c}^u F(c^u)\right]_{c_-^u}^{c_+^u}$$

[30] It can be easily shown that they are all satisfied in equilibrium.

[31] In particular, the integral is strictly positive for $c^u<c_+^u$ since the integrand function is positive (as long as production occurs in equilibrium) and $c_*^u(c^u)>c^u$, while it vanishes for $c^u=c_+^u$ as $c_*^u(c_+^u)=c_+^u$.

$$-\int_{c_-^u}^{c_+^u} F\left(c^u\right) \frac{d}{dc^u}\left[\int_{c^u}^{c_*^u(c^u)} \frac{3\alpha - 3c - \widetilde{c}^u - 2a\left(\widetilde{c}^u\right)}{4\beta} d\widetilde{c}^u\right] dc^u. \tag{63}$$

Notice that the first addend in (63) vanishes since $c_*^u\left(c_+^u\right) = c_+^u$ and $F\left(c_-^u\right) = 0$. If we apply some properties of the integrals and the Torricelli-Barrow theorem, we may rewrite

$$\frac{d}{dc^u}\left[\int_{c^u}^{c_*^u(c^u)} \frac{3\alpha - 3c - \widetilde{c}^u - 2a\left(\widetilde{c}^u\right)}{4\beta} d\widetilde{c}^u\right]$$

$$= \frac{d}{dc^u}\left[\int_{c^u}^{k} \frac{3\alpha - 3c - \widetilde{c}^u - 2a\left(\widetilde{c}^u\right)}{4\beta} d\widetilde{c}^u + \int_{k}^{c_*^u(c^u)} \frac{3\alpha - 3c - \widetilde{c}^u - 2a\left(\widetilde{c}^u\right)}{4\beta} d\widetilde{c}^u\right]$$

$$= -\frac{1}{4\beta}\left(3\alpha - 3c - c^u - 2a\left(c^u\right)\right) + \frac{d}{dc^u}\left[\int_{k}^{c_*^u(c^u)} \frac{3\alpha - 3c - \widetilde{c}^u - 2a\left(\widetilde{c}^u\right)}{4\beta} d\widetilde{c}^u\right], \tag{64}$$

where k is a constant which belongs to $\left(c^u, c_*^u\left(c^u\right)\right)$.

The Torricelli-Barrow theorem and the chain rule imply that the second addend in (64) is equal to

$$\frac{d}{dc^u}\left[\int_{k}^{c_*^u(c^u)} \frac{3\alpha - 3c - \widetilde{c}^u - 2a\left(\widetilde{c}^u\right)}{4\beta} d\widetilde{c}^u\right]$$

$$= \frac{dc_*^u\left(c^u\right)}{dc^u}\frac{1}{4\beta}\left[3\alpha - 3c - c_*^u\left(c^u\right) - 2a\left(c_*^u\left(c^u\right)\right)\right]$$

$$= \frac{1}{3}\frac{1}{4\beta}\left[3\alpha - 3c - \left(\frac{2}{3}\left(\alpha - c\right) + \frac{1}{3}c^u\right) - 2a\left(c_*^u\left(c^u\right)\right)\right]$$

$$= \frac{1}{36\beta}\left[7\left(\alpha - c\right) - c^u - 6a\left(c_*^u\left(c^u\right)\right)\right]. \tag{65}$$

Substituting (65) into (64) yields

$$\frac{d}{dc^u}\left[\int_{c^u}^{c_*^u(c^u)} \frac{3\alpha - 3c - \widetilde{c}^u - 2a\left(\widetilde{c}^u\right)}{4\beta} d\widetilde{c}^u\right] = -\frac{1}{4\beta}\left(3\alpha - 3c - c^u - 2a\left(c^u\right)\right)$$

$$+\frac{1}{36\beta}\left[7\left(\alpha - c\right) - c^u - 6a\left(c_*^u\left(c^u\right)\right)\right]$$

$$= -\frac{1}{36\beta}\left[20\left(\alpha - c\right) - 8c^u - 18a\left(c^u\right) + 6a\left(c_*^u\left(c^u\right)\right)\right]. \quad (66)$$

Finally, replacing (66) into (63) implies

$$\int_{c_-^u}^{c_+^u}\int_{c^u}^{c_*^u(c^u)} \frac{3\alpha - 3c - \widetilde{c}^u - 2a\left(\widetilde{c}^u\right)}{4\beta} d\widetilde{c}^u f\left(c^u\right) dc^u$$

$$= \int_{c_-^u}^{c_+^u} F\left(c^u\right) \frac{1}{36\beta}\left[20\left(\alpha - c\right) - 8c^u - 18a\left(c^u\right) + 6a\left(c_*^u\left(c^u\right)\right)\right] dc^u. \quad (67)$$

Using (67) the maximization problem in (62) becomes

$$\max_{a(c^u)} \int_{c_-^u}^{c_+^u} \left\{\frac{\beta}{2}\left[\frac{3\alpha - 3c - c^u - 2a\left(c^u\right)}{4\beta}\right]^2\right.$$

$$+\left[\alpha - \frac{1}{4}\left(3\alpha - 3c - c^u - 2a\left(c^u\right)\right) - c - a\left(c^u\right)\right]$$

$$\cdot\frac{1}{4\beta}\left(3\alpha - 3c - c^u - 2a\left(c^u\right)\right) + \left(a\left(c^u\right) - c^u\right)\frac{1}{4\beta}\left(3\alpha - 3c - c^u - 2a\left(c^u\right)\right)$$

$$\left. - \left(1 - \gamma\right)\frac{1}{36\beta}\left[20\left(\alpha - c\right) - 8c^u - 18a\left(c^u\right) + 6a\left(c_*^u\left(c^u\right)\right)\right]\frac{F\left(c^u\right)}{f\left(c^u\right)}\right\} f\left(c^u\right) dc^u. \quad (68)$$

Observe that

$$\frac{da\left(c_*^u\left(c^u\right)\right)}{da\left(c^u\right)}=\frac{da\left(c_*^u\left(c^u\right)\right)}{da\left(c^u\right)}\cdot\frac{dc^u}{dc^u}=\frac{\frac{da(c_*^u(c^u))}{dc^u}}{\frac{da(c^u)}{dc^u}}=\frac{1}{3}\frac{\frac{da(c_*^u(.))}{dc_*^u(.)}}{\frac{da(c^u)}{dc^u}}=\frac{1}{3},$$

as long as $a\left(.\right)$ is linear. Then, from (68) the first-order condition for $a\left(c^u\right)$ is

$$-\frac{1}{8\beta}\left(3\alpha-3c-c^u-2a\left(c^u\right)\right)-\frac{1}{8\beta}\left(3\alpha-3c-c^u-2a\left(c^u\right)\right)$$

$$-\frac{1}{8\beta}\left(\alpha-c+c^u-2a\left(c^u\right)\right)+\frac{1}{4\beta}\left(3\alpha-3c-c^u-2a\left(c^u\right)\right)$$

$$-\frac{1}{2\beta}\left(a\left(c^u\right)-c^u\right)+\left(1-\gamma\right)\frac{4}{9\beta}\frac{F\left(c^u\right)}{f\left(c^u\right)}=0,$$

from which we find the optimal access charge in (23) of Proposition 4 in the paper.

The quantity supplied by the incumbent is the same as that with complete information in (9) of Proposition 1, since it does not depend on the access charge and thus cannot be distorted by the regulator in equilibrium. Substituting (23) into (44) yields the quantity produced by the entrant, which corresponds to (24) in Proposition 4. From (9) and (24) we derive the downstream market price in (25) in Proposition 4. Using (2), we find the consumer surplus, which amounts to

$$\overline{CS}^{LS}=\frac{1}{2\beta}\left[\alpha-c-c^u-\frac{8}{9}\left(1-\gamma\right)H\left(c^u\right)\right]^2. \tag{69}$$

Using (9), (23) and (25) we get the incumbent's profit in (26) of Proposition 4. If we take the difference between (26) and (11) we obtain

$$\Delta\pi_I^{LS}\equiv\overline{\pi}_I^{LS}-\pi_I^{LS}=-\frac{4}{9\beta}\left(\alpha-c-c^u\right)\left(1-\gamma\right)H\left(c^u\right)\leq 0. \tag{70}$$

Following the same procedure we find the profit of the entrant, i.e (27) in Proposition 4. Subtracting (11) from (27) yields after some manipulations

$$\Delta\pi_E^{LS} \equiv \overline{\pi}_E^{LS} - \pi_E^{LS} = -\frac{8}{9\beta}(1-\gamma)H(c^u)\left[\alpha - c - c^u - \frac{8}{9}(1-\gamma)H(c^u)\right] \leq 0, \tag{71}$$

where the last inequality comes from $\overline{q}_E^{LS} \geq 0$ in (24), which implies that the term in square brackets in (71) must be positive. Comparing (70) and (71) immediately yields $\left|\Delta\pi_E^{LS}\right| \geq \left|\Delta\pi_I^{LS}\right|$ (as $\overline{q}_E^{LS} \geq 0$).

Substituting (23) into (ICC_N^{LS}) and knowing that $\pi_N^{LS}(c_*^u(c^u)) = 0$ in equilibrium, we find the profit of the input monopolist, which is given by (28) in Proposition 4. As shown in Appendix IV.B, (28) satisfies the standard property of decreasing monotonocity in c^u. From (28) we can now compute the subsidy received by the monopolist in (29) of Proposition 4. Using (26), (27), (28), (29) and (69), we find after some computations the asymmetric-information social welfare in (30) of Proposition 4.

Appendix IV.A

We derive now the incentive compatibility constraint (ICC_N^{LS}) of the network provider for the profit function in (3) and show that this represents a local necessary condition for incentive compatibility which is also globally sufficient.

The class of global incentive compatible mechanisms must satisfy the following set of conditions

$$\pi_N(c^u, c^u) \equiv \pi_N(c^u) \geq \pi_N(\widehat{c}^u, c^u), \text{ for any } \widehat{c}^u, c^u \in \left[c_-^u, c_+^u\right]. \tag{72}$$

In order to induce a firm not to lie, the profit $\pi_N(c^u, c^u)$ obtained by telling the truth has to be at least as great as the profit $\pi_N(\widehat{c}^u, c^u)$ that the firm could get for any report $\widehat{c}^u$.

Following the Baron (1989) approach, we use (3) and rewrite $\pi_N(\widehat{c}^u, c^u)$ as

$$\pi_N(\widehat{c}^u, c^u) = [a(\widehat{c}^u) - c^u]\, Q(\widehat{c}^u) + S(\widehat{c}^u) = \pi_N(\widehat{c}^u) + (\widehat{c}^u - c^u)\, Q(\widehat{c}^u), \tag{73}$$

where $\pi_N(\widehat{c}^u) \equiv \pi_N(\widehat{c}^u, \widehat{c}^u)$. Substituting $\pi_N(\widehat{c}^u, c^u)$ from (73) into (72) and combining terms yields

$$\pi_N(c^u) - \pi_N(\widehat{c}^u) \geq (\widehat{c}^u - c^u)\, Q(\widehat{c}^u), \text{ for any } \widehat{c}^u, c^u \in \left[c_-^u, c_+^u\right]. \tag{74}$$

Reversing the roles of c^u and $\widehat{c}^u$ implies

$$\pi_N(c^u) - \pi_N(\widehat{c}^u) \leq (\widehat{c}^u - c^u) Q(c^u), \text{ for any } \widehat{c}^u, c^u \in \left[c^u_-, c^u_+\right]. \tag{75}$$

Since (74) and (75) must hold simultaneously for any $\widehat{c}^u, c^u \in \left[c^u_-, c^u_+\right]$, we may write

$$(\widehat{c}^u - c^u) Q(\widehat{c}^u) \leq \pi_N(c^u) - \pi_N(\widehat{c}^u) \leq (\widehat{c}^u - c^u) Q(c^u). \tag{76}$$

If we divide the inequalities in (76) by $\widehat{c}^u - c^u > 0$ and take the limit as $\widehat{c}^u \to c^u$, we get by applying de l'Hospital theorem

$$\frac{d\pi_N(c^u)}{dc^u} = -Q(c^u). \tag{77}$$

Since a derivative is a local property of a function, (77) is a *local* condition which indicates that for any incentive compatible mechanism the profit of the firm viewed across the possible types is a decreasing function of c^u. By integrating both sides in (77) over $[c^u, c^u_*(c^u)]$, we find the local necessary condition for the incentive compatibility (ICC_N^{LS}) seen in the paper

$$\pi_N(c^u) = \pi_N(c^u_*(c^u)) + \int_{c^u}^{c^u_*(c^u)} Q(\widetilde{c}^u) d\widetilde{c}^u, \tag{78}$$

where $Q(\widetilde{c}^u) = \frac{3\alpha - 3c - \widetilde{c}^u - 2a(\widetilde{c}^u)}{4\beta}$ from (9) and (44).

If the firm's profit function satisfies the sorting (or Spence-Mirrlees) condition $\frac{\partial^2 \pi_N(Q,c^u)}{\partial Q \partial c^u} < 0$ ($\frac{\partial^2 \pi_N(Q,c^u)}{\partial Q \partial c^u} > 0$), then the function $Q(c^u)$ is implementable, or globally incentive compatible, if it is monotone nonincreasing (nondecreasing). In equilibrium we have $\pi_N(c^u_*(c^u)) = 0$, so condition (78) boils down to $\pi_N^{LS}(c^u) = \int_{c^u}^{c^u_*(c^u)} Q(\widetilde{c}^u) d\widetilde{c}^u$. Since $\frac{\partial^2 \pi_N^{LS}(Q,c^u)}{\partial Q \partial c^u} = \frac{\partial}{\partial c^u}\left[\frac{\partial}{\partial Q}\left(\int_{c^u}^{c^u_*(c^u)} Q(\widetilde{c}^u) d\widetilde{c}^u\right)\right] = \frac{\partial}{\partial c^u}\left[c^u_*(c^u) - c^u\right] = \frac{1}{3} - 1 = -\frac{2}{3} < 0$, then condition (78) is *globally* incentive compatible as $Q(c^u)$ is nonincreasing (sufficient condition for this is the standard assumption of increasing hazard rate).

Appendix IV.B

Taking the derivative of $\overline{\pi}_N^{LS}$ with respect to c^u yields

$$\frac{d\overline{\pi}_N^{LS}}{dc^u} = \frac{d}{dc^u}\left[\int_{c^u}^{c_*^u(c^u)} \frac{1}{\beta}\left(\alpha - c - \widetilde{c}^u - \frac{8}{9}(1-\gamma)H(\widetilde{c}^u)\right) d\widetilde{c}^u\right]$$

$$= \frac{d}{dc^u}\left[\int_{c^u}^{k} \frac{1}{\beta}\left(\alpha - c - \widetilde{c}^u - \frac{8}{9}(1-\gamma)H(\widetilde{c}^u)\right) d\widetilde{c}^u\right.$$

$$\left. + \int_{k}^{c_*^u(c^u)} \frac{1}{\beta}\left(\alpha - c - \widetilde{c}^u - \frac{8}{9}(1-\gamma)H(\widetilde{c}^u)\right) d\widetilde{c}^u\right], \qquad (79)$$

where k is a constant which belongs to interval $(c^u, c_*^u(c^u))$. If we apply the Torricelli-Barrow theorem and the chain rule, we may rewrite (79) as follows

$$\frac{d\overline{\pi}_N^{LS}}{dc^u} = -\frac{1}{\beta}\left[\alpha - c - c^u - \frac{8}{9}(1-\gamma)H(c^u)\right]$$

$$+\frac{dc_*^u(c^u)}{dc^u}\frac{1}{\beta}\left[\alpha - c - c_*^u(c^u) - \frac{8}{9}(1-\gamma)H(c_*^u(c^u))\right]$$

$$= -\frac{1}{\beta}\left[\alpha - c - c^u - \frac{8}{9}(1-\gamma)H(c^u)\right]$$

$$+\frac{1}{3\beta}\left[\alpha - c - \left(\frac{2}{3}(\alpha - c) + \frac{1}{3}c^u\right) - \frac{8}{9}(1-\gamma)H(c_*^u(c^u))\right]. \qquad (80)$$

Combining terms in (80) implies

$$\frac{d\overline{\pi}_N^{LS}}{dc^u} = -\frac{8}{9\beta}\left[(\alpha - c - c^u) - (1-\gamma)H(c^u) + \frac{1}{3}H(c_*^u(c^u))\right]. \qquad (81)$$

As $\overline{q}_E^{LS} \geq 0$ in (24), the expression in square brackets in (81) is positive, so $\overline{\pi}_N^{LS}$ is decreasing in c^u.

Appendix V

The existence of asymmetric information does not change the outcomes at the last two stages of the regulatory game. Hence, still applying the backward induction procedure, we substitute (51) and (52) into (4) and write down the regulator's maximization problem as

$$\max_{a(c^u),S(c^u)} \int_{c_-^u}^{c_+^u} \left\{ \frac{\beta}{2} \left[3\frac{\alpha - c - a(c^u)}{4\beta} \right]^2 \right.$$

$$+ \left[\alpha - \frac{3}{4}(\alpha - c - a(c^u)) - c - a(c^u) \right] \frac{3}{4\beta}(\alpha - c - a(c^u))$$

$$\left. +\gamma \left[(a(c^u) - c^u) \frac{3}{4\beta}(\alpha - c - a(c^u)) + S(c^u) \right] - S(c^u) \right\} f(c^u)\, dc^u \quad (82)$$

$$s.t. \quad (PC_C),\ (PC_E),\ (PC_I),\ (PC_N)$$

and

$$\pi_N(c^u, c^u) \equiv \pi_N(c^u) \geq \pi_N(\widehat{c}^u, c^u), \text{ for any } \widehat{c}^u, c^u \in \left[c_-^u, c_+^u\right].$$

The last condition represents the incentive compatibility constraint of the network provider. As shown in Appendix V.A, under ownership separation this can be written as

$$\pi_N^{OS}(c^u) = \pi_N^{OS}\left(c_+^u\right) + \int_{c^u}^{c_+^u} 3\frac{\alpha - c - a(\widetilde{c}^u)}{4\beta} d\widetilde{c}^u. \qquad (\mathrm{ICC}_N^{OS})$$

We can ignore all the participation constraints but (PC_N).[32] After substituting (ICC_N^{OS}) into the objective function in (82), we replace from (3) the choice variable $S(c^u)$ with $\pi_N^{OS}\left(c_+^u\right)$ and integrate by parts so as to get

$$\max_{a(c^u),\pi_N^{OS}\left(c_+^u\right)} \int_{c_-^u}^{c_+^u} \left\{ \frac{\beta}{2} \left[3\frac{\alpha - c - a(c^u)}{4\beta} \right]^2 + \left[\alpha - \frac{3}{4}(\alpha - c - a(c^u)) - c - a(c^u) \right] \right.$$

[32] It can be easily seen that they are all satisfied in equilibrium.

$$\cdot \frac{3}{4\beta}\left(\alpha - c - a\left(c^{u}\right)\right) + \left(a\left(c^{u}\right) - c^{u}\right)\frac{3}{4\beta}\left(\alpha - c - a\left(c^{u}\right)\right)$$

$$-\left(1-\gamma\right)\frac{3}{4\beta}\left(\alpha - c - a\left(c^{u}\right)\right)H\left(c^{u}\right) - \left(1-\gamma\right)\pi_{N}^{OS}\left(c_{+}^{u}\right)\Bigg\}f\left(c^{u}\right)dc^{u} \quad (83)$$

$s.t.$ (PC_N).

Since the objective function in (83) is decreasing in $\pi_{N}^{OS}\left(c_{+}^{u}\right)$, the regulator finds it optimal to give zero profits to the most inefficient firm ($\overline{\pi}_{N}^{OS}\left(c_{+}^{u}\right) = 0$), still satisfying ($\text{PC}_N$).

From (83) the first-order condition for $a\left(c^{u}\right)$ is equal to

$$-\frac{9}{16\beta}\left(\alpha - c - a\left(c^{u}\right)\right) - \frac{3}{16\beta}\left(\alpha - c - a\left(c^{u}\right)\right) - \frac{3}{16\beta}\left(\alpha - c - a\left(c^{u}\right)\right)$$

$$+\frac{3}{4\beta}\left(\alpha - c - a\left(c^{u}\right)\right) - \frac{3}{4\beta}\left(a\left(c^{u}\right) - c^{u}\right) + \frac{3}{4\beta}\left(1-\gamma\right)H\left(c^{u}\right) = 0,$$

which yields the optimal access charge in (31) of Proposition 5 in the paper. Replacing (31) into (51), we get the output supplied by the downstream incumbent in (32) of Proposition 5. If we substitute (31) into (52) we derive the quantity produced by the entrant in (33) of Proposition 5. Plugging (32) and (33) into (1) yields the price in the downstream market in (34) of Proposition 5. Using (2), we derive consumer surplus, which is given by

$$\overline{CS}^{OS} = \frac{1}{2\beta}\left[\alpha - c - c^{u} - \left(1-\gamma\right)H\left(c^{u}\right)\right]^{2}. \quad (84)$$

Replacing (31), (32) and (34) into (5), we find the profit of the incumbent firm in (35) of Proposition 5. If we take the difference between (35) and (18) we obtain

$$\Delta\pi_{I}^{OS} \equiv \overline{\pi}_{I}^{OS} - \pi_{I}^{OS} = \frac{2}{9\beta}\left(1-\gamma\right)H\left(c^{u}\right)\left[\left(1-\gamma\right)H\left(c^{u}\right) - 2\left(\alpha - c - c^{u}\right)\right] \leq 0, \quad (85)$$

where the last inequality comes from the fact that the downstream quantities in (32) and (33) are nonnegative.

Following the same procedure, we find the profit of the entrant, i.e. (36) in Proposition 5. Subtracting (19) from (36) yields

$$\Delta\pi_E^{OS} \equiv \overline{\pi}_E^{OS} - \pi_E^{OS} = \frac{1}{9\beta}(1-\gamma) H(c^u)\left[(1-\gamma) H(c^u) - 2(\alpha - c - c^u)\right] \leq 0. \tag{86}$$

It is immediate to see from (85) and (86) that $\left|\Delta\pi_I^{OS}\right| > \left|\Delta\pi_E^{OS}\right|$. Substituting (31) into (ICC_N^{OS}) we find the monopolist's profit, which corresponds to (37) in Proposition 5. From (3) we derive the subsidy received by the monopolist in (38) of Proposition 5. Substituting (35), (36), (37), (38) and (84) into (4), we derive after some computations the asymmetric-information social welfare, which amounts to (39) in Proposition 5.

Appendix V.A

To derive (ICC_N^{OS}), which represents a local necessary condition of the incentive compatibility, we follow exactly the same procedure as that in Appendix IV.A, but in the end we integrate (77) over $\left[c^u, c_+^u\right]$ so as to get

$$\pi_N^{OS}(c^u) = \pi_N^{OS}\left(c_+^u\right) + \int_{c^u}^{c_+^u} Q(\widetilde{c}^u)\, d\widetilde{c}^u, \tag{87}$$

where $Q(\widetilde{c}^u) = \frac{3}{4\beta}\left[\alpha - c - a(\widetilde{c}^u)\right]$ from (51) and (52).

In equilibrium we have $\pi_N^{OS}\left(c_+^u\right) = 0$, so condition (87) boils down to $\pi_N^{LS}(c^u) = \int_{c^u}^{c_+^u} Q(\widetilde{c}^u)\, d\widetilde{c}^u$. Since $\frac{\partial^2 \pi_N^{OS}(Q,c^u)}{\partial Q \partial c^u} = \frac{\partial}{\partial c^u}\left[\frac{\partial}{\partial Q}\left(\int_{c^u}^{c_+^u} Q(\widetilde{c}^u)\, d\widetilde{c}^u\right)\right] = \frac{\partial}{\partial c^u}\left(c_+^u - c^u\right) = 0 - 1 = -1 < 0$, then (87) is globally incentive compatible as $Q(c^u)$ is nonincreasing (sufficient condition for this is the increasing hazard rate).

Appendix VI

After taking the expected value of (28) and (37) we can write their difference $\Delta E\left[\overline{\pi}_N\right] \equiv E\left[\overline{\pi}_N^{LS}\right] - E\left[\overline{\pi}_N^{OS}\right]$ as follows

$$\Delta E\left[\overline{\pi}_N\right] = \int_{c_-^u}^{c_+^u} \int_{c^u}^{c_*^u(c^u)} \frac{1}{\beta}\left[\alpha - c - \widetilde{c}^u - \frac{8}{9}(1-\gamma) H(\widetilde{c}^u)\right] d\widetilde{c}^u f(c^u)\, dc^u$$

$$-\int_{c_-^u}^{c_+^u}\int_{c^u}^{c_+^u}\frac{1}{\beta}\left[\alpha-c-\widetilde{c}^u-(1-\gamma)H\left(\widetilde{c}^u\right)\right]d\widetilde{c}^u f\left(c^u\right)dc^u. \tag{88}$$

After integrating by parts, (88) becomes

$$\Delta E\left[\overline{\pi}\right]=\int_{c_-^u}^{c_+^u}\frac{H}{\beta}\left[\frac{1}{3}\left(\alpha-c-c_*^u\left(c^u\right)-\frac{8}{9}\left(1-\gamma\right)H\left(c_*^u\left(c^u\right)\right)\right)\right.$$

$$\left.-\left(\alpha-c-c^u-\frac{8}{9}\left(1-\gamma\right)H\left(c^u\right)\right)\right]f\left(c^u\right)dc^u$$

$$-\int_{c_-^u}^{c_+^u}\frac{H}{\beta}\left[\alpha-c-c^u-(1-\gamma)H\left(c^u\right)\right]f\left(c^u\right)dc^u. \tag{89}$$

Summing and subtracting by $\frac{1}{9}\left(1-\gamma\right)H\left(c_*^u\left(c^u\right)\right)$, we can rewrite (89) after some computations as follows

$$\Delta E\left[\overline{\pi}\right]=-\int_{c_-^u}^{c_+^u}\frac{H}{9\beta}\left[\left(1-\gamma\right)\left(H\left(c_*^u\left(c^u\right)\right)-H\left(c^u\right)\right)\right.$$

$$\left.+3\left(\alpha-c-c_*^u\left(c^u\right)-\frac{11}{9}\left(1-\gamma\right)H\left(c_*^u\left(c^u\right)\right)\right)\right]f\left(c^u\right)dc^u<0, \tag{90}$$

i.e. $E\left[\overline{\pi}_N^{LS}\right]<E\left[\overline{\pi}_N^{OS}\right]$. The last inequality in (90) arises from the fact that the expression in square brackets is positive since it is the sum of two positive terms. The first one is positive as the hazard rate is increasing $\left(c_*^u\left(c^u\right)>c^u\right)$ and the second one is also positive as $\overline{q}_E^{LS}\geq 0$ in (24) for every $c^u\in\left[c_-^u,c_+^u\right]$ and then also for $c_*^u\left(c^u\right)\in\left[c_-^u,c_+^u\right]$ in place of c^u.

Appendix VII

Taking the expected difference $\Delta E\left[\overline{W}\right]\equiv E\left[\overline{W}^{LS}\right]-E\left[\overline{W}^{OS}\right]$ between (30) and (39) yields

$$\Delta E\left[\overline{W}\right] = \int_{c_-^u}^{c_+^u} \left\{ \frac{1}{2\beta} \left[(\alpha - c - c^u)^2 - \frac{64}{81} (1-\gamma)^2 H^2(c^u) \right] \right.$$

$$\left. -(1-\gamma) \int_{c^u}^{c_*^u(c^u)} \frac{1}{\beta} \left[\alpha - c - \widetilde{c}^u - \frac{8}{9}(1-\gamma) H(\widetilde{c}^u) \right] d\widetilde{c}^u \right\} f(c^u)\, dc^u$$

$$-\int_{c_-^u}^{c_+^u} \left\{ \frac{1}{2\beta} \left[(\alpha - c - c^u)^2 - (1-\gamma)^2 H^2(c^u) \right] \right.$$

$$\left. -(1-\gamma) \cdot \int_{c^u}^{c_+^u} \frac{1}{\beta} \left[\alpha - c - \widetilde{c}^u - (1-\gamma) H(\widetilde{c}^u) \right] d\widetilde{c}^u \right\} f(c^u)\, dc^u. \quad (91)$$

Combining and manipulating terms in (91) implies

$$\Delta E\left[\overline{W}\right] = (1-\gamma) \int_{c_-^u}^{c_+^u} \left\{ \int_{c_*^u(c^u)}^{c_+^u} \frac{1}{\beta} \left[\alpha - c - \widetilde{c}^u - (1-\gamma) H(\widetilde{c}^u) \right] d\widetilde{c}^u \right.$$

$$\left. + \frac{1}{9\beta}(1-\gamma) \left[\frac{17}{18} H^2(c^u) - \int_{c^u}^{c_*^u(c^u)} H(\widetilde{c}^u)\, d\widetilde{c}^u \right] \right\} f(c^u)\, dc^u. \quad (92)$$

Notice that a sufficient condition for (92) to be positive for $\gamma \in [0,1)$ is that the expression in big square brackets is also positive. Integrating by parts yields

$$\int_{c_-^u}^{c_+^u} \int_{c^u}^{c_*^u(c^u)} H(\widetilde{c}^u)\, d\widetilde{c}^u f(c^u)\, dc^u = \left[\int_{c^u}^{c_*^u(c^u)} H(\widetilde{c}^u)\, d\widetilde{c}^u \cdot F(c^u) \right]_{c_-^u}^{c_+^u}$$

$$-\int_{c_-^u}^{c_+^u} F(c^u) \frac{d}{dc^u} \left[\int_{c^u}^{c_*^u(c^u)} H(\widetilde{c}^u)\, d\widetilde{c}^u dc^u \right]$$

$$= \int_{c_-^u}^{c_+^u} F(c^u) \left[H(c^u) - \frac{1}{3} H(c_*^u(c^u)) \right] dc^u, \quad (93)$$

where the last equality arises from the Torricelli-Barrow theorem and the chain rule. Using (93), the sufficient condition for (92) to be positive becomes after summing and subtracting by $\frac{1}{3}H(c^u)F(c^u)$ as follows

$$\int_{c_-^u}^{c_+^u} \frac{17}{18} H^2(c^u) f(c^u)\, dc^u >$$

$$\int_{c_-^u}^{c_+^u} \left[\frac{2}{3} H(c^u) F(c^u) - \frac{1}{3} F(c^u) \left(H\left(c_*^u(c^u)\right) - H(c^u) \right) \right] dc^u. \quad (94)$$

As $H(c^u) \equiv \frac{F(c^u)}{f(c^u)}$, it is immediate to see that the expression on the left-hand side is greater than the first addend on the right-hand side. The increasing monotonicity of the hazard rate implies that the term in round brackets on the right-hand side is positive (as $c_*^u(c^u) > c^u$), so we can conclude that (94) is always satisfied.

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