Vertical Integration and Costly Demand Information in Regulated Network Industries*

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Abstract

We study how vertical integration in regulated network industries affects the acquisition and transmission of socially valuable information on demand. We consider a regulated upstream monopoly with downstream unregulated Cournot competition and demand uncertainty. Demand information serves to set the access price and to foster competition in the unregulated segment but demand realizations can be observed at some cost only by the upstream monopolist; information acquisition is also unobservable.

We show that vertical integration favours acquisition of demand information because of the transmission of information generated by the public nature of the regulatory mechanism. This holds both when access to information is easier for the upstream firm and when it is easier for downstream firms.

Keywords: Access price regulation, Information acquisition, integration, separation, vertically-related industries

JEL Classification: D82, D83, L5.

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1 Introduction

Over the last thirty years, in most network industries there has been a trend towards the opening of segments of the business to competition. In Europe competition was introduced in the late 1990s whereas liberalization in the US and Britain has its provenance in the early 1980s. At the same time, the regulator's role has been restricted to setting the price at which entrants can obtain access to the networks and to decide whether to allow the incumbent firm to continue to operate in the competitive segment.

Access policy and structural reforms have been crucial for the development of competition in network industries. The price at which entrants can obtain access to the networks (such as access to electricity distribution or origination and termination of calls in the case of telecommunications) is a key determinant of the gains secured by pro-competitive policies. As a result considerable attention has been devoted to the design and implementation of access pricing regimes (see Vogelsang 2003 for an in depth discussion).

At the same time, different regulatory measures have been taken with regard to the vertical organization of network industries and in particular the downstream integration of input suppliers. The structural reforms to combat dominance and promote competition during the 1980's and the 1990's led to a separation of the transmission grid from generation in the electricity industry (England and Wales), to a divestiture of transportation service and supply of gas in the gas industry and to a structural separation of local network from long-distance market in the telecommunications industry (A&T in the US in 1982). In the US the large integrated utilities that historically have dominated the electricity industry are undergoing rapid restructuring with federal and some state policies promoting vertical separation.

Despite these reforms, integration remains a viable option. In the US the 1996 Telecommunication Act, has removed the restrictions that kept the Regional Bell Operating Companies out of the long-distance market. In continental Europe dominant regulated firms have been left integrated as it has been viewed it as more appropriate to address competition concerns through action by sector regulator (see e.g. Oftel, 2001 and also Cowan, 2001 for an in depth discussion) and through accounting separation. Accounting separation entails separate profit statements and balance sheets for the separate entities managing different segments of the business. Forms of separation intermediate between structural separation and accounting separation have also been considered.[1] In the US existing electricity utilities exhibit enormous structural differences, ranging from pure distribution to complete integration of generation and distribution.

In the context of a regulated upstream naturally monopolistic sector and a downstream unregulated sector, the economics literature has shown that vertical integration can be anti-competitive. It can make it difficult to create a level playing field in the downstream market because of the incentives of the integrated firm to increase its rivals' costs. The firm may degrade the quality of the input to harm downstream competitors (Armstrong and Sappington, 2007) or it may exaggerate its cost in order to convince the regulator to set a higher access price (Vickers, 1995).

Vertical integration can however alter the performance of the industry in opposite ways. When the access price is greater than the marginal cost of the input, an integrated firm faces lower cost in the downstream market than its rivals. This generally yields a greater output in the downstream market and higher welfare than under separation. Vertical integration can also lead to a reduction in total fixed costs due to a lower number of suppliers entering the downstream market, to better coordination between investments in the upstream and downstream markets (Vickers, 1995) and to efficiency gains from economies of scope (Kwoka, 2002).

In this paper, we focus our attention on another aspect of network industries which may have an impact on the desirability of vertical integration, namely demand uncertainty. Network industries are characterized by volatile demand conditions and accurate demand forecasts are critical to the performance of the

[1] This is the case of the 'operational' or 'functional' separation that has been achieved in the UK and it is increasingly being discussed in Europe. Functional separation entails separate divisions dealing with separate services (retail and non-retail and access and non-access). See Cave (2006) for a discussion.

competitive sector and to ensure coordination of different segments of the industry.[2] In regulated network industries, demand information is also useful for designing optimal access policy which in turn helps the development of competition in the unregulated segment. Information however may be accessible more easily by some firms than by others and incentives to acquire and to transmit the information may vary with the industry structure.

Consider the electricity sector. Demand information in the electricity industry is needed in order to set capacity requirements and to reduce the risk of bankruptcy of the entire system and to meet universal service obligations (continuity of supply in time and space). On account of the demand insensitivity to price, the rigidity of supply and the properties of electricity transmission, an imbalance of supply and demand at any one location on an electricity grid can threaten the stability of the entire grid and disrupt delivery of the product. With minor exceptions power cannot be stored and must be produced the instant it is consumed. Failure of generation to meet demand will result in blackouts. However, as discussed by Borenstein (2002), the demand for electricity is difficult to forecast. The industrial use of electricity varies with the level economic growth, the technological change and the number and type of firms using electricity as an input for their production. The demand of electricity from residential consumers is affected by weather conditions and the distribution of consumers type. Consumers of electricity are heterogeneous and some consumers need no interruption of service whilst others are willing to accept interruptability. Demand forecasts thus require costly predictions over the level of industrial use of electricity and knowledge of the distribution of consumers' types. To ensure efficient responses to both predictable and unpredictable events, some policy analysts have argued that centralized operation of generation and transmission may be necessary (see e.g., Michaels, 2006).

Accurate demand estimation is critical to good performance also in the telecommunications industry. Whilst twenty years ago the boundaries of the telecommunications industry were stable and well defined, now a rapidly chang-

[2] A number of studies incorporate uncertainty in the future revenue to be derived from providing the final good, see for example Clark and Easaw (2007).

ing technology has generated a supply of rapidly changing mix of services with a highly fluctuating demand for existing services. Demand information can then help to design a network compatible with the services offered and to make adequate investment in infrastructure modernization.[3]

In this paper we investigate how vertical integration in regulated network industries affects the acquisition of socially valuable information on demand and how this in turn affects the desirability of vertical integration. We show that vertical integration strengthens the incentives of firms to acquire demand information and that this increases social welfare. This holds both when access to information is easier for upstream firms and when it is easier for downstream firms.

We consider a stylized model with an industry characterized by an upstream market, which is a regulated natural monopoly, and an unregulated downstream market with Cournot competition, homogenous products and demand uncertainty. Following current practice, we assume that the access charge is the only instrument available for the regulator to regulate the industry and we consider optimal access price regulation. The downstream demand is random and information on its realization is valuable to the regulator for the choice of the access price and it is valuable to the downstream firms for the choice of output. We compare the performance of two industrial structures: integration, where the upstream firm is integrated with a downstream firm, and separation, where the upstream firm does not operate in the downstream market.

We start by assuming that information on demand can only be acquired by the upstream monopolist. In the benchmark case where information is costly but once acquired it becomes public knowledge, either integration or separation can be optimal, depending on the parameters but not on the problem of inducing information acquisition by the upstream firm.

Instead, when information is privately acquired and information acquisition is unobservable, other things equal, integration does better than separation.

[3] Demand information can also affect investment incentives in network quality of competing operators using the rival's network for call termination. For a model of invetment in network quality see Valletti and Cambini (2003).

With separation, information revelation by the upstream monopolist is cheap talk and demand information has no value for the upstream monopolist. Only if the firm operates also in the downstream market will it value information acquisition. Vertical integration thus makes the payoff of the upstream monopolist state-dependent creating value for information acquisition over the realized state. This result is somewhat in line with empirical evidence. Using a data set of U.S. electric utilities that differ widely in their degree of vertical integration, Kwoka (2002) estimates that cost savings from vertical integration are substantial. Among other factors, he finds that demand information matters. There are economies from scope generated from better information about downstream load for purposes of determining future capacity requirements. Furthermore, integration helps to accomplish energy balance at all times by allowing real-time management of power flows from the generating units and from large users whose supply may be curtailed to maintain system balance and face unexpected demand shocks.[4]

The problem of inducing information acquisition by the upstream monopolist reverses the result that is obtained in the economics literature when only asymmetric information matters, result that would also be obtained in our setting should information acquisition be observable. With observable information acquisition, compared to the benchmark, separation does better than integration. This is because of an 'informational externality' that arises when information on demand is transmitted to the downstream firm via the public nature of the regulatory mechanism. When the upstream monopolist produces in the downstream market, it has incentive to use its information to induce a contraction in the rival's output and increase its own downstream profits. In a similar vein the economics literature has shown that vertical integration exacerbates the incentives of the upstream monopolist to misreport cost information (Vickers,1995). Thus whether or not vertical integration helps the informational problem depends on whether information is freely available or not.

[4] A number of other studies investigate the relationship between the vertical integration of electricity transmission and distribution and utilities' cost. Most studies show that vertical integration improves economic efficiency. See Michaels (2006) for a discussion.

In the second part of the paper we relax the assumption that only the upstream firm can acquire demand information and we consider the possibility of information acquisition by the unregulated downstream firm. We obtain two main results. First, we show that incentives to acquire information remain stronger under integration than under separation because the value of information for a downstream firm under separation is lower than the value of information for the regulated upstream monopolist under integration. This is due to the fact that the upstream monopolist is regulated and that, as the regulatory mechanism is public, the information acquired by the upstream monopolist is automatically transmitted to its rival in the downstream market. Other things equal, information transmission reduces the profit of the upstream firm because it increases the correlation of firms' strategies in the downstream market. To compensate the firm for the consequent loss in profits, the regulator must design an access price schedule that reflects demand changes in such a way as to reduce overall the correlation of firms' strategies in the downstream market. This in turn boosts the upstream monopolist's incentives to acquire information compared to an unregulated downstream firm.

In this respect our result stands in contrast with the literature on information sharing about a common value in an unregulated Cournot market (see Raith, 1996; for a general model). In that context knowledge by a rival firm of its own profit function leads to higher correlation of strategies and thus reduces the incumbent's profit so that there is no incentive for a firm to transmit information about demand to the rival. In our setting, instead, the opposite occurs because of the role played by the public nature of the regulatory mechanism.

The second result that we obtain is that information acquisition by a downstream firm is less valuable for social welfare than information acquisition by the upstream monopolist. This is because information acquired by the upstream monopolist is transmitted to the downstream firms via the regulation mechanism that sets the access price. Instead, information acquired by an unregulated downstream firm remains private as this firm is unregulated.

Apart from being related to the literature on vertical integration in regulated network industries with imperfect competition in the downstream market, our paper is also related to the literature on information acquisition. The problem of information acquisition on demand has been so far investigated in unregulated industries. Hauk and Hurkens (2000) discuss information acquisition in Cournot markets and compare the case where information acquisition is observable by the rival and when it is not. Hurkens and Vulkan (2001) study the relationship between entry decisions and information gathering by potential entrants, whilst Dimitrova and Schlee (2003) analyze how potential entry affects the incentives of the incumbent monopolist to acquire information on demand.

The impact of the information acquisition problem on the design and performance of regulatory mechanisms has been analyzed in the case where the uncertainty is about costs. See for example Cremer Khalil and Rochet, (1998) for the case of optimal regulation and Iossa and Stroffolini (2002) for the case of price cap regulation. In Iossa and Legros (2004) instead information acquisition concerns the value of the underlying asset and property rights are shown to increase incentives to acquire information. We contribute to this literature by showing how information acquisition problems matter for the organization of network industries. We also consider information acquisition on demand.

The rest of the paper is organized as follows. In section 2 we set up the model. In section 3 we discuss the benchmark case where information acquisition is observable and acquired information can be made public at no additional cost. Section 4 analyzes the standard case where information acquisition is verifiable but the information is privately observed by the upstream monopolist, which also serves as benchmark. Section 5 considers unobservable information acquisition, whilst section 6 studies information acquisition by the affiliate. Section 7 concludes the paper and provides some policy prescriptions. All proofs missing from the text are in an appendix

2 The model

We consider an industry characterized by an upstream regulated natural monopoly and a downstream unregulated market with Cournot competition, homogenous products and demand uncertainty. The production in the downstream market requires an essential input (e.g. an essential facility), produced in the upstream market. We compare two industrial structures: Integration (I) and Separation (S). I indicates a situation where the upstream monopolist is allowed to produce, through a subsidiary, also in the downstream market while under S it is excluded. The number of firms in the downstream market is fixed and equal to two in both industrial structures; only one firm - in addition to the upstream monopolist - owns the technology required to produce the output. Thus the difference between the two industrial structures is solely that under S the downstream firm that was subsidiary of the upstream monopolist is now an independent firm. This allows us to obtain sharp prediction and has no qualitative impact on our results.

We consider optimal access regulation. The upstream market is regulated through a transfer given to the upstream monopolist and an access price paid to the upstream monopolist by the firm(s) in the downstream market for the utilization of the essential input. The technology used to produce the downstream output is the same under I and S and it only requires the essential input. Thus, the upstream monopolist's marginal cost of production of the final good is the marginal cost of the essential input, since the access price paid by its subsidiary is just an internal transfer, while for the rival the marginal cost of production of the final good is the access price. Therefore, there is a cost advantage either for the upstream monopolist or for the rival firm in the downstream market depending on whether the regulated access price is greater or lower than the marginal cost of production of the essential input. We assume that the upstream monopolist and its rival are equally efficient in the downstream market and normalize to zero both the marginal cost and the fixed cost of production.

The downstream market is characterized by a linear inverse demand function: $P(Q,\theta) = \theta - Q + \varepsilon$, where θ, with $\theta \in \left[\underline{\theta}, \overline{\theta}\right]$, is a parameter of adverse selection; it has density function $f(\theta)$ and distribution function $F(\theta)$ satisfying the following assumption $\frac{\partial}{\partial\theta}(\frac{1-F(\theta)}{f(\theta)}) \leq 0$. $f(\theta)$ and $F(\theta)$ are common knowledge. ε is a random error with zero mean. The parameter θ can be interpreted either as the willingness to pay of consumers with preferences distributed according to $f(\theta)$ or as the level of market demand with realizations distributed according to $f(\theta)$. We denote by θ_0 and by σ^2 the mean value and the variance of the distribution of θ, respectively.

The realization of θ can be privately observed at some cost K by the upstream monopolist. In most of the paper we assume that information acquisition is prohibitively costly for the regulator and for the other firms. The regulator observes quantities and price but he cannot infer the true value of θ because of the noise ε. The informational advantage of the upstream monopolist stems from it being the incumbent. In Section 6, we relax this assumption and discuss the possibility that the downstream firm that was once a subsidiary of the upstream monopolist retains the technical expertise and know-how to acquire information on θ also at cost K. In this model, the social value of information on demand stems from it serving to determine the optimal access price and to adjust production in the downstream market.

Consider now the payoff of the firms, net of the information-acquisition cost. Under I, the profit function of the upstream monopolist is given by[5]

$$\Pi_I^M = (\theta - Q_I)q^M + a_I q^R + T_I \tag{1}$$

where $Q_I = q^M + q^R$ and q^M and q^R denote the quantity produced by the upstream monopolist and by the rival firm in the downstream market, respectively. T_I and a_I denote the transfer received from the regulator and the access price paid by the rival. The profit function of the rival is instead

$$\Pi_I^R = (\theta - Q_I - a_I)q^R \tag{2}$$

Under S, the profit function of the upstream monopolist is given by

$$\Pi_S^M = a_S Q_S + T_S \tag{3}$$

[5] In the rest of this paper $\Pi(.)$ indicares the expected profit with respect to ε.

where $Q_S = 2q_S$ and q_S denotes the quantity produced by a downstream firm. T_S and a_S denote the transfer received from the regulator and the access price paid by the downstream firms. The profit of a downstream firm is

$$\Pi_S^D = (\theta - Q_S - a_S)q_S \tag{4}$$

The objective function of the regulator is given by the social value of the net consumer surplus plus the firms' profits. Let $S(\theta, Q)$ denote the gross consumer surplus, with $S'(\theta, Q) = P(\theta, Q)$ and $S''(\theta, Q) \leq 0$, and let $\lambda > 0$ denote the shadow cost of public funds. The objective function of the regulator under I, when there is information acquisition, can then be written as

$$W_I = S(\theta, Q_I) - P(\theta, Q_I)Q_I - (1 + \lambda)T_I + \Pi_I^M + \Pi_I^R - K$$

Under S, when there is information acquisition, the regulator's objective function is

$$W_S = S(\theta, Q_S) - P(\theta, Q_S)Q_S - (1 + \lambda)T_S + \Pi_S^M + 2\Pi_S^D - K$$

The timing of the game is the following. 1) Nature chooses θ; 2) the regulator offers the upstream monopolist the menu of contracts $\{a_I(\theta), T_I(\theta)\}$ under I and $\{a_S(\theta), T_S(\theta)\}$ under S; 3) the monopolist decides whether to acquire information on θ by investing K, and it observes θ if it does; 4) the monopolist decides whether to accept the contract offered by the regulator; the firms in the downstream market simultaneously choose their quantities; the transfer T_h and the access price a_h ($h = I, S$) are paid.

3 Benchmark 1: costly public information

As benchmark, suppose that information acquisition is observable and information can be made public at no additional cost. In this case we show in the Appendix that for K sufficiently low the optimal regulatory mechanism induces the upstream monopolist to acquire information, the information is then made public and used to adjust production in the downstream market and to set the access price. Comparing I and S we then obtain as follows.

Proposition 1 *Under costly public information, there exists a level of* λ*, denoted by* $\lambda^{*} > 0$*, such that for* $\lambda \geq \lambda^{*}$*, under* I *expected welfare and the value of information are at least as high than under* S*. The opposite statement holds for* $\lambda < \lambda^{*}$*.*

Under both I and S, the regulator uses the access price to reduce the need for distortionary taxation and to increase the output of the firms in the downstream market which is subotimal. A higher access price raises access revenue but lowers the output in the downstream market. When λ is high, reducing distortionary taxation is particularly important and thus the social value of the revenue obtained by the upstream monopolist in downstream market under I is high. This effect favours I. When λ is low, reducing the level of distortionary taxation is less important and the main concern of the regulator becomes to increase production in the downstream market. This calls for a low access price and it favours S. Overall, either I or S can be optimal, depending on the parameters but not on the problem of inducing information acquisition by the upstream firm.

For future references, we denote by $a_I^*(\theta, \lambda)$ and $a_S^*(\theta, \lambda)$ the optimal access prices under I and under S with costly public information. Further, we let $EW_h^*(\theta, \lambda, K)$ denote the expected maximum value function under costly public information and information acquisition and $w_h^*(\theta_0, \lambda)$ the welfare function under no information acquisition. Finally we use $K_h^*(\lambda)$ to denote the value of K such that for $K \leq K_h^*(\lambda)$ the optimal regulatory mechanism induces information acquisition.

4 Benchmark 2: observable information acquisition with private information

In this section we assume that information acquisition is observable but the information is privately observed by the upstream monopolist. We assume that the regulatory mechanism is public information and so is the report $\widehat{\theta}$ made by the monopolist. This is realistic, given the lack of control on the activities of regulators if we assumed otherwise.[6] In this case, the regulator can demand the upstream monopolist to incur cost K to acquire information and use a direct truthful regulatory mechanism of the form: $\{a_h(\theta), \Pi_h^M(\theta)\}$, with $h = I, S$.

4.1 Integration

Under I consider the game that is played in the downstream market. Given the demand parameter announced by the upstream monopolist $\widehat{\theta}$ and the access price set by the regulator, $a_I(\widehat{\theta})$, in the downstream market the upstream monopolist chooses q^M to maximize

$$\Pi_I^M(\theta, \widehat{\theta}) = (\theta - q^M - q^R)q^M + a_I(\widehat{\theta})q^R + T_I(\widehat{\theta}) \tag{5}$$

whilst the rival chooses q^R so as to maximize

$$\Pi_I^R(\widehat{\theta}) = (\widehat{\theta} - q^M - q^R - a_I(\widehat{\theta}))q^R$$

Since in equilibrium $\widehat{\theta} = \theta$, the rival learns the realization of demand from the report of the monopolist and uses it to set its own output. Thus, there is an informational externality: the information that the upstream monopolist acquires becomes public through the regulatory mechanism. This affects the strategy of the rival and, through this, the payoff of the upstream firm.

In particular, from the above two equations the equilibrium quantities produced in the downstream market for any given level of $\widehat{\theta}$ and $a_I(\widehat{\theta})$ are

$$q^M(\theta, \widehat{\theta}) = \frac{3\theta - \widehat{\theta} + 2a_I(\widehat{\theta})}{6}; \; q^R(\widehat{\theta}) = \frac{\widehat{\theta} - 2a_I(\widehat{\theta})}{3}$$

and, by substituting for $q^M(\theta, \widehat{\theta})$ and $q^R(\widehat{\theta})$ in (5), the incentive compatibility constraints are

$$\begin{aligned} IC1 \quad &: \quad \frac{\partial \Pi_I^M(\theta)}{\partial \theta} = q^M(\theta, \widehat{\theta} = \theta) = \frac{\theta + a_I(\theta)}{3} > 0 \\ IC2 \quad &: \quad \frac{\partial^2 \Pi_I^M(\theta)}{\partial \theta \partial \widehat{\theta}} \Rightarrow \frac{\partial a_I(\theta)}{\partial \theta} > \frac{1}{2}. \end{aligned}$$

[6] It is also possible to show that if $\widehat{\theta}$ were confidential information, under plausible assumptions ensuring strict monotonicity, its value could be easily inferred from the value of $a_h(\widehat{\theta})$.

The firm has incentives to underreport the realization of θ to benefit from the increase in downstream revenues when demand is higher. Further, the informational externality raises incentives to misreport. Indeed, suppose that the rival were informed and set its output on basis of the true realization of θ so that no informational externality arises. Then, $q^M(\theta,\widehat{\theta}) = \frac{\theta + a(\widehat{\theta})}{3}$, $q^R(\theta,\widehat{\theta}) = \frac{\theta - 2a(\widehat{\theta})}{3}$ and

$$\frac{\partial \Pi_L^M(\theta,\widehat{\theta})}{\partial \theta} = q^M(\theta,\widehat{\theta}) - \frac{\partial q^R}{\partial \theta}\left(q^M(\theta,\widehat{\theta}) - a(\widehat{\theta})\right) = \frac{2\theta + 5a(\widehat{\theta})}{9}$$

As in the case where the rival is uninformed, the higher θ, the greater the downstream revenues that the upstream monopolist can obtain for any given level of the rival's output. This effect is positive and given by $q^M(\theta,\widehat{\theta})$. However, when the rival is informed, the higher θ the higher its output in the downstream market. This in turn generates two effects: it reduces the profits of the upstream monopolist in the downstream market $(-\frac{\partial q^R}{\partial \theta} q^M(\theta,\widehat{\theta}))$ and it increases the access revenues due to greater output by the rival $\frac{\partial q^R}{\partial \theta} a(\widehat{\theta})$. The sum of these two terms is negative. In other words, the informational externality increases the informative rent that must be granted to the upstream monopolist in order to induce truthful revelation. The upstream monopolist, by underreporting θ, prevents the rival from adjusting its output according to the true realization of θ and so it can benefit from the whole increase in downstream revenues due to the higher level of demand instead of only a part of it as in the case of an informed rival.

Consider now the optimal mechanism. Let $E\Pi_I^M(\theta, a_I(\theta))$ denote the expected rent of the upstream monopolist for given access price, which has to ensure that the upstream monopolist finds it profitable to acquire information about θ

$$E\Pi_I^M(\theta, a_I(\theta)) \geq K \qquad \text{((IR-IA))}$$

and let μ be the non-negative multiplier associated with it.

Lemma 1 *Let $\widehat{a}_I(\theta, \mu(K))$ denote the optimal access price under Integration and observable information acquisition, where $\widehat{a}_I(\theta, \mu(K)) \leq a_I^*(\theta, \lambda)$ and $\frac{\partial \widehat{a}_I(\theta, \mu(K))}{\partial \mu(K)} > 0$ and let also $K_I^0 \equiv E\Pi_I^M(\theta, \widehat{a}_I(\theta, \mu = 0))$ and $\widehat{K}_I^1 \equiv E\Pi_I^M(\theta, \widehat{a}_I(\theta, \mu = \lambda))$*

with $\widehat{K}_I^1 > \widehat{K}_I^0$*. Under observable information acquisition: (i) for* $K \leq \widehat{K}_I^0$*,* $\mu(K) = 0$*; (ii) for* $K \in (\widehat{K}_I^0, \widehat{K}_I^1)$*,* $\mu(K)$ *solves* $E\Pi_I^M(\theta, \widehat{a}_I(\theta, \mu)) = K$*; with* $\mu(K) \in (0, \lambda)$ *and* $\mu'(K) \geq 0$*; and (iii) for* $K \geq \widehat{K}_I^1$*,* $\mu(K) = \lambda$*.*

When K is low (i.e. $K < \widehat{K}_I^0$), the expected rent - evaluated at $a_I^*(\theta, \lambda)$ - is greater than K. Thus the $(IR - IA)$ constraint is slacking and we are in a standard adverse selection problem. To reduce this rent, which has a social cost of λ, the regulator introduces a downward distortion in the access-price schedule with respect to the perfect information allocation for all $\theta < \overline{\theta}$. This leads to $\widehat{a}_I(\theta, \mu = 0)$. As K rises, eventually it reaches a level, $\widehat{K}_I^0$, where the expected rent, evaluated at $\widehat{a}_I(\theta, \mu = 0)$, is equal to K. From this value of K onwards, the $(IR - IA)$ constraint starts to be binding. Thus there is no longer a need to minimize the informative rent, and in fact, the firm needs to receive an additional transfer to help it cover the cost of acquiring information. The distortion in the access price is gradually reduced, and as K reaches the value $\widehat{K}_I^1$, the access price schedule returns to its full information level, $a_I^*(\theta, \lambda)$. For even higher K, the firm is compensated for the information acquisition cost with an increase in the monetary transfer.

Let $\widehat{W}_I(\theta, \lambda, K)$ denote the maximum value function under observable information acquisition when there is information acquisition and $E\widehat{W}_I(\theta, \lambda, K)$ its expectation. If instead there is no information acquisition, the maximum value function is given by $w_I^*(\theta_0, \lambda)$. We denote by $\widehat{K}_I^*$ the level of K such that for $K > \widehat{K}_I^*$ information acquisition is suboptimal. Since $E\widehat{W}_I(.) \leq EW_I^*(.)$, we have $\widehat{K}_I^* \leq K_I^*(\lambda)$.

Now consider how the unobservability of θ affects the performance of regulation. Let $\widehat{\Delta}^I(.) \equiv \max\{EW_I^*(\theta, \lambda, K), w_I^*(\theta_0, \lambda)\} - \max\{E\widehat{W}_I(\theta, \lambda, K), w_I^*(\theta_0, \lambda)\}$ and without loss of generality consider the case where $\widehat{K}_I^1 \leq K_I^*(\lambda)$. The following lemma is then obtained.

Lemma 2 *Asymmetric information reduces expected welfare under Integration for all* $K < \widehat{K}_I^1$*, whilst it has no effects for* $K \geq \widehat{K}_I^1$*. In particular: (i)* $\widehat{\Delta}^I(K) > 0$*; with* $\frac{\partial \widehat{\Delta}^I(K)}{\partial K} = \mu(K) - \lambda < 0$ *for all* $K < \widehat{K}_I^1$*; (ii)* $\widehat{\Delta}^I(K) = 0$ *for* $K \geq \widehat{K}_I^1$*.*

Lemma 2 is easily understood in light of the fact that for $K < \widehat{K}_I^1$ information acquisition is optimal but it is costly in terms of expected rent due to asymmetric information. For $K \geq \widehat{K}_I^1$, the rent is insufficient to cover information acquisition cost. The constraint $(IC1)$ starts to slack, whilst the $(IR-IA)$ starts to bind as under costly public information leading to $EW_I^*(\theta, \lambda, K) = E\widehat{W}_I(\theta, \lambda, K)$. It also follows from this that $\widehat{K}_I^* = K_I^*(\lambda)$.

4.2 Separation

Following the same reasoning as under I, consider the game played in the downstream market when the value of demand parameter announced by the upstream monopolist is $\widehat{\theta}$. Anticipating that in equilibrium $\widehat{\theta} = \theta$, a downstream firm chooses q_S so as to maximize

$$\Pi_S^D(\widehat{\theta}) = (\widehat{\theta} - 2q_S - a_S(\widehat{\theta}))q_S$$

yielding $q_S(\widehat{\theta}) = \frac{\widehat{\theta} - a_S(\widehat{\theta})}{3}$ and profit for the upstream monopolist equal to

$$\Pi_S^M(\widehat{\theta}) = a_S(\widehat{\theta})2q_S(\widehat{\theta}) + T_S(\widehat{\theta}) \tag{6}$$

It follows that $\frac{\partial \Pi_S^M(\theta)}{\partial \theta} = 0$, i.e., the profits of the upstream monopolist are independent of the true realization of θ. Intuitively, under S the profits of the upstream monopolist are equal to the access revenues which only depend on the quantities produced by the downstream firms. These quantities are in turn independent of θ : since the downstream firms are ignorant, their output decisions are taken on the basis of the reported realization of θ and not of its true realization. It follows that, for any reported realization of θ,the upstream monopolist's profits obtainable under the corresponding regulatory contract $\left\{a_S(\widehat{\theta}), T_S(\widehat{\theta})\right\}$ are the same, whatever the true realization of θ; hence, the upstream monopolist has no incentives to misreport the value of θ. The regulator can then extract the private information about the true realized level of demand from the upstream monopolist at no cost and the optimal mechanism is the same as it is under costly public information.

This result is due to the informational externality generated by the public nature of the regulatory mechanism which, as under I, transmits information to the uninformed downstream firms. However, under S as opposed to I, this informational externality works in favour of the truthful reporting of θ. Indeed, suppose for a moment that the downstream firms were informed and set their outputs according to the true realization of θ. The upstream monopolist's profit function would become

$$\Pi_S^M(\theta, \widehat{\theta}) = a(\widehat{\theta})Q(\theta, \widehat{\theta}) + T_S(\widehat{\theta})$$

with $Q(\theta, \widehat{\theta}) = \frac{2\theta - 2a(\widehat{\theta})}{3}$ and

$$\frac{\partial \Pi_S^M(\theta, \widehat{\theta})}{\partial \theta} = a(\widehat{\theta})\frac{\partial Q}{\partial \theta} > 0$$

That is, by underreporting θ the incumbent could gain greater access revenues corresponding to the true realization of θ. Therefore, with no information transmission, it would be costly for the regulator to extract information about demand from the upstream monopolist.

Let $E\widehat{W}_S(\theta, \lambda, K)$ denote the expected maximum value function under observable information acquisition when the upstream monopolist acquires information. In light of the above we have

$$E\widehat{W}_S(\theta, \lambda, K) = EW_S^*(\theta, \lambda, K) \tag{7}$$

For $K > \widehat{K}_S^*$ there is no information acquisition and the maximum value function is given by $w_S^*(\theta_0, \lambda)$; it follows from (7) that $\widehat{K}_S^* = K_S^*(\lambda)$. Let $\widehat{\Delta}^S(.) = \max\{EW_S^*(\theta, \lambda, K), w_S^*(\theta_0, \lambda)\} - \max\{E\widehat{W}_S(\theta, \lambda, K), w_S^*(\theta_0, \lambda)\}$denote the welfare effect of asymmetric information under S.

Lemma 3 $\widehat{\Delta}^S = 0$ *for all* K*: under Separation, asymmetric information has no effect on welfare.*

4.3 Comparison

From Lemmas 2 and 3 we have seen that for all $K < \widehat{K}_I^1$ asymmetric information creates a distortion in the optimal mechanism under I but not under S, whilst for all $K \geq \widehat{K}_I^1$ under both I and S there is no distortion. The Proposition below is then obtained.

Proposition 2 *When information acquisition is costly but observable, asymmetric information on demand generates a bias in favour of Separation for all* $K < \widehat{K}_I^1$*, whilst it has no effect on the welfare comparison between Integration and Separation for all* $K \geq \widehat{K}_I^1$*. The bias in favour of Separation over the range* $K < \widehat{K}_I^1$ *decreases with* K*. In particular: (i)* $\widehat{\Delta}_I(K) - \widehat{\Delta}_S > 0$ *and* $\frac{\partial(\widehat{\Delta}^I(K) - \widehat{\Delta}^S)}{\partial K} = \mu(K) - \lambda < 0$ *for* $K < \widehat{K}_I^1$*, where* $\mu(K)$ *is defined in Lemma 1. (ii)* $\widehat{\Delta}_I(K) - \widehat{\Delta}_S = 0$ *for* $K \geq \widehat{K}_I^1$*.*

5 Unobservable information acquisition

5.1 Integration

In this section we consider the case where information acquisition is unobservable. An additional constraint needs to be added to the regulator's maximization program (PL-1) compared to the case where information acquisition is observable. This is the incentive compatibility constraint on information acquisition, $(IC - IA)$, which ensures that, under the optimal mechanism, the upstream monopolist prefers to incur K to become informed about the realization of θ rather than remain uninformed.

In this context, it is easy to show that with linear demand function an uninformed upstream monopolist would choose the contract corresponding to the mean of the distribution of θ : $\{a(\theta_0), T(\theta_0)\}$. By using equations $(IC1)$ and (12), the $(IC - IA)$ is then given by[7]

$$E\Pi_I^M(\theta) - \Pi_I^M(\theta_0) = \int_{\underline{\theta}}^{\overline{\theta}} \frac{\theta + a_I(\theta)}{3}(1 - F(\theta) - \Upsilon_{\theta<\theta_0})d\theta \geq K \qquad \text{(IC-IA)}$$

where Υ is a dummy variable with $\Upsilon = 1$ if $\theta < \theta_0$ and $\Upsilon = 0$ if $\theta \geq \theta_0$. Let ν denote the non-negative multiplier of the $(IC - IA)$, we obtain the following Lemma.

Lemma 4 *Let* $\widetilde{K}_I = \frac{1}{6}(1 + \frac{\partial \widehat{a}_I(\theta,\mu=0)}{\partial\theta})\sigma^2 < K_I^0$*. Let* $\widetilde{a}_I(\theta, \nu)$ *denote the optimal access price schedule under Integration and unobservable information acquisition, where* $\widetilde{a}_I(\theta, \nu) > \widehat{a}_I(\theta, \mu)$ *for* $\theta > \theta_0$ *and* $\widetilde{a}_I(\theta, \nu) < \widehat{a}_I(\theta, \mu)$ *for* $\theta < \theta_0$*. Under Integration and unobservable information acquisition: (i)* $\nu(K) = 0$ *for*

$K \le \widetilde{K}_I$, *(ii)* $\nu(K) \in (0, \lambda]$ *and solves*

$$E\Pi_I^M(\theta, \nu) - \Pi_I^M(\theta_0) = K \tag{8}$$

with $\nu'(K) > 0$ *and* $v(K) \ge \mu(K)$, *for* $K > \widetilde{K}_I$.

Information is valuable to the upstream monopolist since it yields an informative rent. For $K \le \widetilde{K}_I$ this informative rent is sufficient to induce information acquisition, the (IC-IA) constraint is slack, and the optimal mechanism remains the same as under observable information acquisition. Instead, from $\widetilde{K}_I$ onwards the (IC-IA) constraint starts to be binding and the optimal mechanism needs to be modified. Depending on whether θ is greater or smaller than θ_0 an increase in $a_I(.)$ has one or two (opposing) effects on the value of information. An increase in $a_I(.)$ increases $E\Pi_I^M(\theta)$ by $(1 - F(\theta))$ and eases the information constraint, but for $\theta \in (\underline{\theta}\ ,\theta_0)$ a unit increase in $a_I(.)$ increase also $\Pi_I^M(\theta_0)$ by a unit and makes the information constraint tighter. Therefore $\widetilde{a}_I(\theta)$ is higher than $\widehat{a}_I(\theta)$ for large values of θ and smaller for low θ which implies a discontinuity at θ_0.

Let $\widetilde{W}_I(\theta, \lambda, K)$ denote the maximum value function under unobservable information acquisition when information acquisition is induced, and let $E\widetilde{W}_I(.)$ denote its expectation. From Lemma 4, we have that $E\widetilde{W}_I(.)$ is decreasing in K and there exists a $\widetilde{K}_I^*$ such that for $K \le \widetilde{K}_I^*$ there is information acquisition and $E\widetilde{W}_I(.)$ is obtained, whilst for $K > \widetilde{K}_I^*$ there is no information acquisition and the maximum value function is given by $Ew_I^*(\theta_0, \lambda) = w_I^*(\theta_0, \lambda)$, where it is immediate that $\widetilde{K}_I^* \le \widehat{K}_I^*$.

Let $\widetilde{\Delta}_I(.) = \max\{E\widehat{W}_I(.), w_I^*(\theta_0, \lambda)\} - \max\{E\widetilde{W}_I(.), w_I^*(\theta_0, \lambda)\}$, that is $\widetilde{\Delta}_I$ denotes the welfare difference under I between the case where information acquisition is observable and the case where it is not observable.

Lemma 5 *Under unobservable information acquisition, (i)* $\widetilde{\Delta}_I = 0$ *for* $K \le \widetilde{K}_I$; *(ii)* $\widetilde{\Delta}_I(K) > 0$, *with* $\frac{\partial \widetilde{\Delta}_I(K)}{\partial K} = \nu(K) - \mu(K)$ *for* $K \in (\widetilde{K}_I, K_I^*(\lambda)]$, *(iii)* $\widetilde{\Delta}_I(K) = 0$ *for* $K > K_I^*(\lambda)$.

When K is low (case (i) in the Lemma), the unobservability of information acquisition does not induce any welfare loss since the firm has incentives to acquire information in order to gain the informational rent. However, as K increases (case (ii)) inducing information becomes costly. The $(IC - IA)$ constraint starts to bind and the regulator starts to distort the mechanism in order to provide the firm with incentives to acquire information. When K increases even further (case (iii)) information acquisition becomes so costly that it is preferable for welfare not to induce it.

5.2 Separation

Consider the value of information for the upstream monopolist under S. Recall that when the downstream firms are ignorant the upstream monopolist's profit is independent on θ, $\frac{\partial \Pi_S^M}{\partial \theta} = 0$, which as we have seen implies that there is no gain for the upstream monopolist from misrreporting the value of the demand parameter. Whilst this is a positive result for the regulator when information acquisition is observable, it becomes problematic when information acquisition is not observable, as the lemma below emphasizes.

Lemma 6 *Under unobservable information acquisition the upstream monopolist never acquires information under Separation.*

Intuitively, since the monopolist cannot extract any informative rent from acquiring information under S, it will have no incentives to invest K in order to learn the value of θ, or to put it differently, since the monopolist does not produce in the downstream market, information revelation is a cheap talk game. It follows from the above lemma that the optimal regulatory mechanism will be given by $\{a_S^*(\theta_0, \lambda), \Pi_S^*(\theta_0)\}$, leading to an expected welfare of $E\widetilde{W}_S(\theta, \lambda, K) = w_S^*(\theta_0, \lambda)$. Then, letting $\widetilde{\Delta}_S(.) = \max\{E\widehat{W}_S(.), w_S^*(\theta_0, \lambda)\} - \max\{E\widetilde{W}_S(.), w_S^*(\theta_0, \lambda)\}$, we obtain the lemma below.

Lemma 7 *(i)* $\widetilde{\Delta}_S(K) > 0$, *for all* $K \leq K_S^*(\lambda)$, *with* $\frac{\partial \widetilde{\Delta}_S(K)}{\partial K} = -(1+\lambda)$ *ii)* $\widetilde{\Delta}_S = 0$ *for all* $K > K_S^*(\lambda)$.

Since there is no information acquisition under S, a welfare loss due to the unobservability of information acquisition will arise whenever information acquisition is socially desirable, i.e. whenever $K \leq K_S^*(\lambda)$.

5.3 Comparison

We now study how the unobservability of information acquisition affects the performance of the two regimes, I and S, compared to a situation where information acquisition is observable by the regulator. The proposition below summarizes our main result.

Proposition 3 *(i) If $\lambda \leq \lambda^*$, unobservability of information acquisition creates a bias in favour of Integration (i.e., $\widetilde{\Delta}_I(K) \leq \widetilde{\Delta}_S(K)$) and this bias is non-increasing in K; (ii) If $\lambda > \lambda^*$, there exists a level of K, denoted by K^*, where $K^* \in (\widetilde{K}_I, \widetilde{K}_I^*)$ such that for $K \leq K^*$ unobservability of information acquisition creates a bias in favour of Integration (i.e., $\widetilde{\Delta}_I(K) \leq \widetilde{\Delta}_S(K)$) and this bias is non-increasing in K. For $K > K^*$ unobservability of information acquisition creates a bias in favour of Separation (i.e., $\widetilde{\Delta}_I(K) \geq \widetilde{\Delta}_S(K)$) and this bias is non-decreasing in K for $K \leq K_S^*(\lambda)$.*

The above proposition follows from a combination of two effects. First, as we have seen in the previous section, it is easier to induce information acquisition under I than under S. Ceteris paribus this creates a bias in favour of I. Intuitively, inducing information acquisition is easier under I than under S because information on θ is more valuable to the firm when it can use this information also to choose output in the product market (as under I) than when it cannot (as under S). Second, the value of information acquisition depends on λ. If $\lambda \leq \lambda^*$ information acquisition is more valuable under S than under I (since $K_S^*(\lambda) \geq K_I^*(\lambda)$, and $\widehat{K}_S^* \geq \widehat{K}_I^*$) and thus more is lost from lack of information under S compared to I. These two effects go in the same direction and explain point (i). Instead, if $\lambda > \lambda^*$, information acquisition is more valuable under I than under S (since $K_S^*(\lambda) < K_I^*(\lambda)$) and the two effects go in opposite direction. Then, for low K information acquisition is valuable under both I and S and a bias arises in favour of I. For high K the opposite is true. This explains point (ii).

6 Information acquisition by the affiliate

Until now we have assumed that the upstream monopolist is the only firm that, at cost K, can acquire information on the realization of θ. However, if we take into account that one of the two downstream firms was an affiliate of the upstream monopolist before the separation, it seems possible that also this firm will have the technology and the know-how to acquire information on θ. In this section we allow for this possibility.

We let the cost of information acquisition for the downstream firm be K and we assume again that information acquisition is unobservable. Contrary to the upstream monopolist, the downstream firm is unregulated and thus the information it acquires will not be transmitted to its rival neither will it be used to set the access price.

Under unobservable information acquisition, the optimal mechanism is the same as when the downstream firm cannot acquire information, and it is given by $\{a_S(\theta_0), \Pi_S^M(\theta_0)\}$. This is because the total output is linear in a_S and the regulator does not know θ at the time of choosing the regulatory mechanism.

In light of this, we derive the incentives of the downstream firm to acquire information. It is easy to show that $q_S^N(\theta_0, a_S) = \frac{\theta_0 - a_S}{3}$ is the quantity produced by an uninformed firm when also the rival is uninformed, whilst $q_S(\theta, \theta_0, a_S) = \frac{\theta}{2} - \frac{\theta_0}{6} - \frac{a_S}{3}$ is the quantity produced by the downstream firm when it acquires information and the rival is uninformed.

Denoting by $\Pi_S^D(\theta, \theta_0, a_S)$ the maximum value function of the downstream firm when it acquires information and the rival is uninformed and by $\Pi_S^D(\theta_0, a_S)$ the expected profit of the firm when it does not acquire information, we obtain the value of information for the downstream firm when the rival is ignorant

$$E\Pi_S^D(\theta, \theta_0, a_S) - \Pi_S^D(\theta_0, a_S) = \frac{\partial^2 \Pi_S^D(\theta, \theta_0, a_S)}{\partial^2 \theta} \frac{\sigma^2}{2} = \frac{\sigma^2}{4} \tag{9}$$

which leads us to the following Proposition.

Proposition 4 *The incentives to acquire information of the affiliate under Separation are lower than the incentives to acquire information of the upstream monopolist under Integration; the affiliate acquiring information on θ for all*

$K \leq \widetilde{K}_S$, where $\widetilde{K}_S = \frac{\sigma^2}{4} < \widetilde{K}_I$.

Before discussing the intuition behind the above proposition we state a related corollary.

Corollary 1 *Unobservability of information acquisition creates a bias in favour of Integration also when the affiliate can acquire information.*

Since the downstream firm is not regulated, its information cannot be used to set the access price which will therefore be set on the basis of the expected value of θ. Further, the access price cannot be used as an instrument to increase the firm's incentives to acquire information. The value of information for the downstream firm is given only by the profitability of adjusting its output level to the realized level of demand. For $K \leq \widetilde{K}_S$, this effect induces information acquisition. However, $\widetilde{K}_S < \widetilde{K}_I$ (where $\widetilde{K}_I$ is defined in Lemma 4) that is, the value of information for the downstream firm under S is smaller than the value of information for the upstream monopolist under I. This is a consequence of the fact that the upstream monopolist is regulated and the regulatory mechanism is public knowledge whilst the downstream firm is not regulated as we explain below.

The value of information for either firm is proportional to the sensitivity of its output to θ since $\frac{\partial^2 \Pi^i(.)}{\partial^2 \theta} = -\frac{\partial q^i}{\partial \theta}$. Under I the acquisition of information has three effects on the upstream monopolist's output: a direct effect, arising from the adjustment of its output level to the true realized level of demand, and two indirect effects, arising from the transmission of information to the rival through the regulatory mechanism.

The first indirect effect is due to the rival adjusting its output to the realized value of demand: the greater θ, the greater the rival's output. This effect increases the correlation of firms' strategies and thus reduces the sensitivity of the upstream monopolist's output to θ. However, the second indirect effect works in an opposite direction and more than compensates the first one. This is due to the incentive compatibility of the regulatory mechanism. Incentive compatibility requires that the sensitivity of the regulated access price be high enough to make the rival's quantity decrease with θ.

To see this, rewrite the $(IC2)$ constraint under I as

$$\frac{\partial^2 \Pi_I^M(\theta)}{\partial\theta\partial\widehat{\theta}} = -\frac{1}{2}\frac{\partial q^R(\theta)}{\partial\theta} = -\frac{1}{6}\left(1 - 2\frac{\partial a_I(\theta)}{\partial\theta}\right) > 0 \tag{10}$$
$$with \ \frac{\partial a_I(\theta)}{\partial\theta} > \frac{1}{2} \iff \frac{\partial q^R(\theta)}{\partial\theta} < 0$$

The access price structure must reflect changes in demand in such as way a to reduce the correlation of firms' strategies in the downstream market and more than compensate the loss in profits due to the transmission of information generated by the public nature of the regulatory mechanism. Instead, under S the information acquired by the unregulated downstream firm, remaining private, is only used to adjust its output to the true realization of θ without affecting its rival's output.

Therefore, on account of the informational externality generated by the regulatory mechanism, the sensitivity of the upstream monopolist's output to θ under I is greater than the sensitivity of the informed downstream firm's output under S.[8] As a result, $\widetilde{K}_S < \widetilde{K}_I$: a regulated upstream monopolist has stronger incentives to acquire information than an unregulated downstream firm.Not only does the affiliate have weaker incentives to acquire information than an upstream monopolist but also, when the affiliate acquires information it does so privately. No socially valuable information transmission to either the rival or the regulator takes place.

7 Conclusions

In this paper we have studied the desirability of allowing an upstream monopolist to operate in the downstream market (Integration) rather than to exclude it (Separation), in the presence of costly demand information. We have shown that asymmetric information on demand favours Separation but unobservability of information acquisition favours Integration. When information on demand can

[8].In particular, let $q^i = \frac{\theta - q^R}{2}$ be the output chosen under Cournot competition by the firm who acquires information, with $i = M$ under I and $i = D$ under S, and with $q^R = \frac{\theta - 2a(\theta)}{3}$ denoting the output of the rival. Then the sensitivity of output of the upstream monopolist firm with respect to θ is given by: $\frac{1}{2}\left(1 - \frac{\partial q^R}{\partial\theta}\right)$, whilst the sensitivity of output of the downstream is $\frac{1}{2}$, since information is not passed onto the rival.

only be acquired by the upstream monopolist, inducing information acquisition is easier under Integration than under Separation because demand information is more valuable to the firm when it can also use this information to choose its output in the product market (as under I) than when it cannot (as under S). Integration is then more likely to be preferable to Separation in industries where demand is uncertain and lack of information on demand can generate very costly service disruptions.

We have also shown that unobservability of information acquisition favours Integration also in the case where information on demand can be acquired by the downstream firm under Separation. This is due to the fact that the upstream monopolist is regulated while the downstream firm is not and that the regulatory mechanism is public knowledge which generates an informational externality that boosts incentive for information acquisition.

Our results imply that the presence of costly but valuable information on demand in network industries provides an argument in favour of vertical Integration of a regulated input supplier. However, if Separation is preferable to Integration for other reasons not analyzed here, information acquisition issues require to regulate the downstream firm (instead of the upstream monopolist) that is most able to acquire information.

We have focused on the case where the number of firms is the same under both Integration and Separation. An extension of our analysis could be to study how the cost of acquiring that technology may affect entry decisions.

8 Appendix

Proof of Proposition 1. Under I, maximization of (1) w.r.t. q^M and of (2) w.r.t. q^R yields the equilibrium variables in the downstream market as function of θ and a_I

$$q^M(\theta, a_I) = \frac{\theta + a_I}{3};\ q^R(\theta, a_I) = \frac{\theta - 2a_I}{3}; Q_I(\theta, a_I) = \frac{2\theta - a_I}{3}; P_I(\theta, a_I) = \frac{\theta + a_I}{3}$$

Similarly, under S maximization of (3) w.r.t. q^S yields

$$q_S(\theta, a_S) = \frac{\theta - a_S}{3}; Q_S(\theta, a_S) = \frac{2\theta - 2a_S}{3}; P_S(\theta, a_S) = \frac{\theta + 2a_S}{3}$$

Let $w_I(\theta, a_I, \lambda) = S(\theta, Q_I) + \lambda P_I q^M + \lambda a_I q^R$ and $w_S(\theta, a_S, \lambda) \equiv S(\theta, Q_S) + \lambda a_S Q_S$, we can write the regulator's maximization program as as

$$\begin{aligned} \max W_h(\theta, a_h, \Pi_h^M, \lambda, K) &\equiv w_h(\theta, a_I, \lambda) - \lambda \Pi_h^M - K \quad \text{h=I,S} \\ s.t. &: \\ E\Pi_h^M(\theta) - K &\geq 0, \qquad \text{h=I,S} \\ \Pi_h^M(\theta) &\geq 0 \text{ for all } \theta \epsilon \left[\underline{\theta}, \overline{\theta}\right] \qquad \text{h=I,S} \end{aligned}$$

We then obtain $E\Pi_h^M(\theta) = K$ and

$$\begin{aligned} a_I^*(\theta, \lambda) &= \frac{(5\lambda - 1)\theta}{1 + 10\lambda} \\ a_S^*(\theta, \lambda) &= \frac{\theta\,(3\lambda - 1)}{2 + 6\lambda} \end{aligned}$$

with $a_h^*(\theta, \lambda)$ increasing in λ.The expected welfare from information acquisition under costly public information is then

$$EW_h^*(\theta, \lambda, K) = Ew_h(\theta, a_h^*(\theta, \lambda), \lambda) - (1 + \lambda)K \tag{11}$$

Instead, if information acquisition does not occur, the expected welfare is $Ew_h^*(\theta_0, \lambda) = w_h^*(\theta_0, \lambda)$, where $w_h^*(\theta_0, \lambda) \equiv Ew_h(\theta, a_h^*(\theta_0, \lambda), \lambda)$, due to linear demand. It follows that under I, information acquisition is optimal if $Ew_I^*(\theta, \lambda) - w_I^*(\theta_0, \lambda) \geq (1 + \lambda)\,K$. By using Taylor expansion

$$Ew_I^*(\theta, \lambda) - w_I^*(\theta_0, \lambda) = \frac{\partial^2 w_I(\theta, \lambda)}{\partial^2 \theta}\frac{\sigma^2}{2} = \frac{1 + 8\lambda + 5\lambda^2}{2(1 + 10\lambda)}\sigma^2$$

which implies that information on demand is socially valuable for $K \leq K_I^*(\lambda) = \frac{1+8\lambda+5\lambda^2}{2(1+\lambda)(1+10\lambda)}\sigma^2$. Similarly, under S information on demand is socially valuable for $K \leq K_S^*(\lambda) = \frac{(1+\lambda)}{2(1+3\lambda)(1+\lambda)}\sigma^2$ to K_I^*.

Now note that $W_S^*(\theta,\lambda,K) = W_I^*(\theta,\lambda,K)$ at $\lambda = 0$, and $\frac{dW_I^*(\theta,\lambda,K)}{d\lambda}\Big|_{\lambda=0} = -\theta^2$, $\frac{dW_S^*(\theta,\lambda,K)}{d\lambda}\Big|_{\lambda=0} = -\frac{\theta}{2}^2$ which implies $W_S^*(\theta,\lambda,K) > W_I^*(\theta,\lambda,K)$ in a neighborhood of $\lambda = 0$. Tedious calculations then give $\frac{d^2W_I^*(\theta,\lambda,K)}{d\lambda^2} - \frac{d^2W_S^*(\theta,\lambda,K)}{d\lambda^2} = b$, where b is a positive constant, which implies that there exists a $\lambda^* > 0$, independent of θ, such that $W_S^*(\theta,\lambda,K) < W_I^*(\theta,\lambda,K)$ for all $\lambda > \lambda^*$, and vice versa. From the above $EW_S^*(\theta,\lambda,K) - w_S^*(\theta_0,\lambda) = EW_I^*(\theta,\lambda,K) - w_I^*(\theta_0,\lambda)$ at $\lambda = 0$ and $\lambda = \lambda^*$, i.e. $K_S^*(\lambda) = K_I^*(\lambda)$ at $\lambda = 0, \lambda = \lambda^*$. Furthermore from the definition of $K_S^*(\lambda)$ and $K_I^*(\lambda)$ it easy to show that they are continuous non-increasing functions of λ with $\left|\frac{\partial K_S^*(\lambda)}{\partial\lambda}\right| < \left|\frac{\partial K_I^*(\lambda)}{\partial\lambda}\right|$ at $\lambda = 0$ and $\left|\frac{\partial K_S^*(\lambda)}{\partial\lambda}\right| > \left|\frac{\partial K_I^*(\lambda)}{\partial\lambda}\right|$ at $\lambda = \lambda^*$; so the result follows.■

Proof of Lemma 1 Using standard techniques, from $(IC1)$, we obtain the expected rent of the upstream monopolist

$$E\Pi_I^M(\theta, a_I(\theta)) = \Pi_I^M(\underline{\theta}) + \int_{\underline{\theta}}^{\overline{\theta}} \frac{\theta + a_I(\theta)}{3}\frac{1-F(\theta)}{f(\theta)}dF(\theta) \tag{12}$$

The regulator's problem is then to determine, for each θ, the couple $(\widehat{a}_I(\theta), \widehat{\Pi}_I^M(\theta))$ which solves

$$\max_{a_I(\theta),\Pi_I^M(\theta)} \int_{\underline{\theta}}^{\overline{\theta}} W_I(\theta, a_I(\theta), \Pi_I^M(\theta), \lambda, K)dF(\theta) \tag{PL-1}$$
$$s.t.: (IR-IA), (IR), (IC1)(IC2)$$

where in $(IR-IA)$, the expected rent is given by (12). Since the objective function of program (PL-1) is strictly concave and the constraint $(IR-IA)$ is linear in a_I and in K, the problem is convex with an unique solution. Neglecting for the moment constraint $(IC2)$, maximization of the the Lagrangian of program (PL-1) w.r.t. a yields

$$-(1+10\lambda)\widehat{a}_I(.) - \theta + 5\lambda\theta - 3(\lambda-\mu)\frac{1-F(\theta)}{f(\theta)} = 0$$

where the SOC and constraint $(IC2)$ are satisfied provided that $-\frac{3}{2} + 5\lambda - 3(\lambda - \mu)\frac{\partial}{\partial\theta}(\frac{1-F(\theta)}{f(\theta)}) \geq 0$. Now, consider the case where $(IR-IA)$ is not binding and

$\mu = 0$. Substituting for $a_I = \widehat{a}_I(\theta, \mu = 0)$ in (12) we obtain $\widehat{K}_I^0$. Thus, $\mu = 0$ is the solution for $K \leq \widehat{K}_I^0$. Substituting for $a_I = \widehat{a}_I(\theta, \mu = \lambda)$ in the same equation, we obtain $\widehat{K}_I^1$.

(i) Since $W_I()$ is strictly concave and the $(IR - IA)$ constraint is linear in a_I and in K, it follows that its value function, denoted by $E\widehat{W}_I$, is concave in K and $\mu(K) = -\frac{\partial E\widehat{W}_I(.)}{\partial K} - 1$. Given the concavity of $E\widehat{W}_I(.)$, $\mu(K)$ is a non-decreasing function of K; for $K \leq \widehat{K}_I^0, E\widehat{W}_I(.)$ is linear in K and $\mu(K) = 0$. (ii)To see that $\mu \leq \lambda$, consider an increase dK in K; a (suboptimal) feasible response by the regulator that would maintain all the constraints satisfied would be to increase all the transfers by dK and to keep the same access price schedule This would decrease its payoff by $(1+\lambda)dK$. Therefore we have $E\widehat{W}_I(\theta, \lambda, K + dK) \geq E\widehat{W}_I(\theta, \lambda, K) - (1+\lambda)dK$ and so $\frac{\partial E\widehat{W}_I(.)}{\partial K} \geq -(1+\lambda)$.(iii) Since, for $K \geq \widehat{K}_I^1, \widehat{a}_I(\widetilde{\theta}, \mu = \lambda) = a_I^*(\theta, \lambda)$ we have $E\widehat{W}_I(\theta, \lambda, K) = EW_I^*(\theta, \lambda, K)$■

Proof of Lemma 2. In light of Lemma 1 we have

$$E\widehat{W}_I(\theta, \lambda, K) = w_I(\theta, \widehat{a}_I(\theta, \mu(K)), \lambda) - \left(\lambda E\Pi_I^M(\theta, \widehat{a}_I(\theta, \mu(K)) + K\right) \quad (13)$$

$$\text{with } \frac{\partial E\widehat{W}_I(\theta, \lambda, K)}{\partial K} = -\left(1 + \mu(K)\right)$$

Now note that $\widehat{\Delta}^I(K) > 0$ for $K \to 0$, since $E\Pi_I^M(\theta, \widehat{a}_I(\theta, \mu = 0)) > K$ and $EW_I(\theta, \widehat{a}_I(\theta, \mu = 0), .) < EW_I(\theta, a_I^*(\theta), .)$ from $a_I^*(\theta) = \arg\max EW_I(\theta, a_I(\theta), .)$ and $a_I^*(\theta, \lambda) \neq \widehat{a}_I(\theta, \mu = 0)$. From (11), (13) and Lemma 1, we then have $\frac{\partial \widehat{\Delta}^I(K)}{\partial K} = -\lambda + \mu(K) \leq 0$. For $K \geq \widehat{K}_I^1$, $EW_I(\theta, \widehat{a}_I(\theta, \mu = \lambda), .) = EW_I(\theta, a_I^*(\theta, \lambda), .)$, since $\widehat{a}_I(\widetilde{\theta}, \mu = \lambda) = a_I^*(\theta, \lambda)$.■

Proof of Lemma 4. The regulator's problem is

$$\max_{a_I(\theta), \Pi_I^M(\theta)} \int_{\underline{\theta}}^{\overline{\theta}} W_I(\theta, a_I(\theta), \Pi_I^M(\theta), \lambda, K) dF(\theta)$$
$$s.t. : (IR - IA), \ (IR), (IC1), (IC2), (IC - IA)$$

Constraint $(IC - IA)$ implies that the constraint $(IR - IA)$ is automatically satisfied and therefore it can be neglected. Neglecting for the moment the constraint ($IC2$), the Lagrangian of the maximization problem becomes

$$\int_{\underline{\theta}}^{\overline{\theta}} (S(\theta, Q_I(\theta, a_I)) + \lambda P(\theta, a_I) q^M(\theta, a_I) + \lambda a_I q^R(\theta, a_I)$$
$$-\lambda q^M(\theta, a_I) \frac{1 - F(\theta)}{f(\theta)} + \nu q^M(\theta, a_I) \frac{1 - F(\theta) - \Upsilon_{\theta < \theta_0}}{f(\theta)} - (\nu + 1) K) dF(\theta)$$

Since the function is strictly concave and the constraint ($IC - IA$) is linear in a_I and in K, the problem is convex with an unique solution. Maximization w.r.t. a yields

$$-(1 + 10\lambda)\widetilde{a}_I(.) - \theta + 5\lambda\theta - 3\lambda \frac{1 - F(\theta)}{f(\theta)} + 3\nu \frac{1 - F(\theta) - \Upsilon_{\theta < \theta_0}}{f(\theta)} = 0$$

where SOC and constraint ($IC2$) are satisfied provided that $-\frac{3}{2} + 5\lambda - 3\lambda \frac{\partial}{\partial\theta}(\frac{1-F(\theta)}{f(\theta)}) + 3\nu \frac{\partial}{\partial\theta}(\frac{1-F(\theta)-\Upsilon_{\theta<\theta_0}}{f(\theta)}) \geq 0$.

(i) Now, let us take the case where the ($IC - IA$) is slacking at the solution to the maximization program, and thus $\nu(K) = 0$. From the ($IR - IA$) and the ($IC - IA$) it follows that ($IR - IA$) cannot be binding. Thus when $\nu(K) = 0$, we have $\mu = 0$, and we obtain that for all $K \leq \widetilde{K}_I$, where $\widetilde{K}_I = E\widehat{\Pi}_I^M(\theta, \mu = 0) - \widehat{\Pi}_I^M(\theta_0, \mu = 0) = \frac{\partial^2 \Pi_I^M(\theta,\mu)}{\partial^2\theta} \frac{\sigma^2}{2} = \frac{1}{6}(1 + \frac{\partial \widehat{a}_I(\theta,\mu=0)}{\partial\theta})\sigma^2$, the optimal mechanism is the same as under observable information. Comparing $\widetilde{K}_I$ with $\widehat{K}_I^0$ from Lemma 1, we have $\widetilde{K}_I < \widehat{K}_I^0$. Instead for $K > \widetilde{K}_I$ the ($IC - IA$) constraint is binding and the ($IR - IA$) can be neglected.

(ii) Following the same reasoning as in the proof of Lemma 1, we have $\nu(K) \leq \lambda$.We now show that $\mu(K) \leq \nu(K)$.for all $K > \widetilde{K}_I$ Suppose by contradiction that there exists a $K > \widetilde{K}_I$, denoted by K_0, such that $\mu(K_0) > \nu(K_0)$. Then since $\nu(K) > \mu(K) = 0$ for $K \leq \widehat{K}_I^0$, $\mu'(K), \nu'(K) \geq 0$ and $\mu''(K), \nu''(K) = 0$ for all K, it follows that $\mu(K) \geq \nu(K)$ for all $K \geq K_0$, and that the level of K such that $\mu(K) = \lambda$, is smaller than the level of K such that $\nu(K) = \lambda$. Take therefore a K where $\nu(K) < \lambda$ and $\mu(K) = \lambda$. From ($IR - IA$), substituting for $\widehat{a}_I$ ($\mu = \lambda$) we have

$$\int_{\underline{\theta}}^{\overline{\theta}} \frac{\theta + \frac{\theta(5\lambda-1)}{1+10\lambda}}{3} (1 - F(\theta)) d(\theta) = K,$$

whilst from $(ICL - IA)$, substituting for $\widetilde{a}_I$ $(\nu < \lambda)$

$$\int_{\underline{\theta}}^{\theta_0} -F(\theta)\frac{\theta + \frac{\theta(5\lambda-1)}{1+10\lambda} - \frac{3}{1+10\lambda}\left(\lambda\frac{1-F(\theta)}{f(\theta)} + \nu(K)\frac{F(\theta)}{f(\theta)}\right)}{3}d\theta + \int_{\theta_0}^{\overline{\theta}} \frac{\theta + \frac{\theta(5\lambda-1)}{1+10\lambda} - \frac{3(\lambda-\nu(K))}{1+10\lambda}\frac{1-F(\theta)}{f(\theta)}}{3}(1-F(\theta))d\theta =$$

and it is immediate that the LHS of the $(IR - IA)$ is greater than the LHS of $(IC - IA)$ implying that it cannot be that they are both binding for that level of K ■

Proof of Lemma 5. The maximum value function is given by

$$\begin{aligned} E\widetilde{W}_I(\theta,\lambda,K) &= Ew_I(\theta,\widetilde{a}_I(\theta,\nu(K)),\lambda) - \lambda E\Pi_I^M(\theta,\widetilde{a}_I(\theta,\nu(K)) - K \\ &\text{with}\frac{\partial E\widetilde{W}_I(\theta,\lambda,K)}{\partial K} = -(1+\nu(K)) \end{aligned}$$

and from Lemmas 1 and 4 we have: $E\widehat{W}_I(.) = E\widetilde{W}_I(.)$ for $K \leq \widetilde{K}_I$ and $\widetilde{K}_I^* \in (\widetilde{K}_I, K_I^*(\lambda))$. For $K \in (\widetilde{K}_I, \widetilde{K}_I^*)$, $\frac{\partial E\widehat{W}_I(.)}{\partial K} - \frac{\partial E\widetilde{W}_I(.)}{\partial K} = -\mu(K) + \nu(K)$, where $\mu(K) = 0$ for all $K \leq \widehat{K}_I^0$, $\mu(K), \nu(K) \leq \lambda$ and $\mu(K) \leq \nu(K)$ for all K. Since $\mu(K) = \lambda$ for all $K \geq \widehat{K}_I^1$, then the level of K such that $\nu(K) = \lambda$ is a $K \in (\widetilde{K}_I, \widehat{K}_I^1]$. From this we have

$$\frac{\partial\widetilde{\Delta}_I}{\partial K} = \begin{cases} \nu(K) > 0 & \text{for} \quad K \in (\widetilde{K}_I, \widehat{K}_I^0] \\ -\mu(K) + \nu(K) > 0 & \text{for} \quad K \in (\widehat{K}_I^0, \widehat{K}_I^1) \\ -\lambda + \lambda = 0 & \text{for} \quad K \in \left[\widehat{K}_I^1, \widetilde{K}_I^*\right) \\ -1 - \lambda & \text{for} \quad K \in \left[\widetilde{K}_I^*, K_I^*(\lambda)\right] \end{cases}$$

if $\widetilde{K}_I^* > \widehat{K}_I^1$. The remaining cases are qualitatively similar.■

Proof of Proposition 3 (i) From Proposition 1 $\lambda \leq \lambda^*$ implies $K_S^*(\lambda) \geq K_I^*(\lambda)$. Then from Lemmas 5 and 7 we have: $\widetilde{\Delta}_I(K) - \widetilde{\Delta}_S(K) = -\widetilde{\Delta}_S(K) < 0$ for all $K \leq \widetilde{K}_I$ and for $K \in (K_I^*(\lambda), K_S^*(\lambda))$, whilst $\widetilde{\Delta}_I(K) - \widetilde{\Delta}_S(K) = 0$ for $K \geq K_S^*(\lambda)$. Then, since the functions $\widetilde{\Delta}_I(K)$ and $\widetilde{\Delta}_S(K)$ are continuous and $\frac{\partial}{\partial K}(\widetilde{\Delta}_I(K) - \widetilde{\Delta}_S(K))$ is non-negative for all $K \in (\widetilde{K}_I, K_I^*(\lambda))$, therefore $\widetilde{\Delta}_I(K) - \widetilde{\Delta}_S(K) < 0$ for all K. (ii) Similar reasoning proves the result when $K_S^*(\lambda) < K_I^*(\lambda)$. ■

Proof of Proposition 4. It follows from (9).

9 References

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