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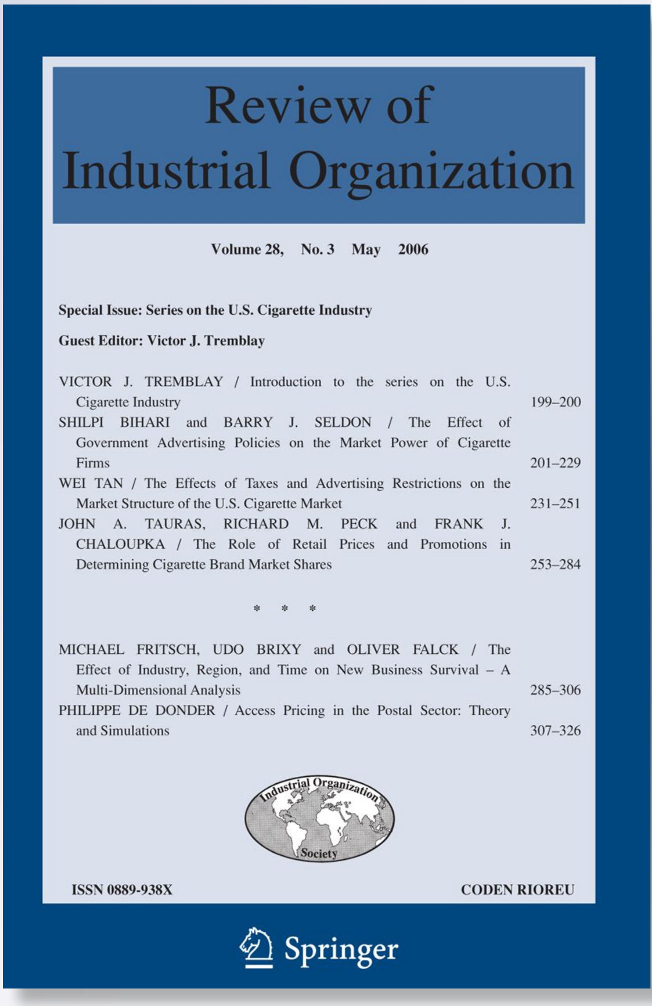

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Abstract We study how vertical integration affects the acquisition and transmission of demand information in regulated network industries. Demand information helps to set the access price, incentivize infrastructure investment, and foster competition in the unregulated downstream market. We show that when demand information is costly and private, the optimal access prices are independent of demand levels. Vertical integration then secures greater welfare in new markets where little demand information is available or where infrastructure cost is low, or when investing is highly risky. In the remaining cases, vertical separation is preferable.

Keywords Access price regulation · Information acquisition · Integration · Separation · Vertically-related industries

JEL Classification D82 · D83 · L5

1 Introduction

Recent technological innovations in network industries have created a supply of new services that require new access infrastructures. But both high infrastructure costs and an uncertain demand for these new services are causing underinvestiment (EU 2009).

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The problem may be exacerbated by the employment of cost-based access regulation, as this leaves demand risk wholly to the investor.[1]

This underinvestment problem raises the issue of how governments can stimulate investment in the infrastructure whilst at the same time ensure that competition will develop over the new network.

In this paper we study how access regulation and industry structure affect the acquisition and transmission of demand information that can help to promote competition and favour new infrastructure investment.

We consider a stylized model with an upstream market, which is a regulated natural monopoly, and an unregulated downstream market with imperfect competition, homogenous products, and demand uncertainty. We compare two industry structures: vertical integration, where the upstream firm is integrated with a downstream firm, and vertical separation, where the upstream firm does not operate downstream.

Our results show that under both industry structures the optimal access prices are independent of realized demand levels. Under vertical separation, demand information is not acquired by the upstream monopolist; under vertical integration it is acquired but kept private.

With this rigidity in the access price regulation, vertical integration may generate a trade-off. On the one hand, the downstream profit made by the upstream monopolist helps to incentivize investments. Ceteris paribus, this increases allocative efficiency. On the other hand, the upstream firm's knowledge of demand realizations may make it more costly for the regulator to induce the firm's participation, resulting in higher access prices.

Vertical integration is then shown to be preferable to vertical separation in new markets where little demand information is available; for low infrastructure cost and when investing is very risky, entry is profitable only for high demand levels.

The rest of the paper is organized as follows: In Sect. 2 we discuss the background; in Sect. 3, the related literature. In Sect. 4 we set up the model; in Sect. 5 we discuss the benchmark case where information is costly but public. Section 6 analyzes the case of costly private information whilst in Sect. 7 we briefly discuss the case where public transfers are allowed. Section 8 considers the case where demand information can affect the decision as to whether to invest in the infrastructure. Section 9 concludes. All proofs missing from the text are in an Appendix.

2 Background

Over the last 30 years, regulatory policies in network industries have been mainly directed towards the promotion of competition. Entry has been promoted through the design of access pricing regimes and through reforms that provide for the (structural, operational, functional, or accounting) separation of the upstream supplier of infrastructure services from the downstream provider of retail services.[2]

[1] Cost-based access regulation is currently the norm across Europe and the US.

[2] See Vogelsang (2003) for an in-depth discussion of access pricing regimes.

Recent technological innovations, especially in the telecommunications industry, have created a supply of new services that require new access infrastructures (the EU calls them "new generation access network", NGA). The NGA networks are wired access networks that consist wholly or in part of optical elements. They can deliver broadband access services with enhanced characteristics compared to those provided over the existing copper networks.

Underinvestment is, however, occurring, due to high infrastructure costs and to the difficulty to forecast the extent to which consumers will take up the new services or their willingness to pay (EU 2009). This poses the question as to how access and industry regulation can balance the dual aims of promoting competition and favouring investments.

Policy makers and regulators are addressing the issue in different ways: In some cases vertical integration is being promoted; in other cases, access price regulation is being reviewed; in yet other cases, subsidies for investment are being given.

For example, in 2005 the US Federal Communication Commission relieved the incumbent telecommunications operators (the former Bell companies) of access regulation and of the structural and functional separation rules that were designed decades earlier for copper access.

The European position has instead mainly kept the role of access price regulation unchanged but promoted more vertical separation via the introduction of accounting separation (Italy) and functional separation (UK). In the UK, Ofcom (2007) has posed the question as to whether to introduce 'demand-based' access prices: setting the price for access services on the basis of realized demand levels, so as to spread risk and incentivize investment.

In Japan and South Korea the government has financed a large amount of the infrastructure investment. Also the European Commission has envisaged the possibility of giving subsidies to private firms to promote investment, given the NGA relevance to economic growth and social cohesion.[3]

3 Related Literature

The economics literature on regulation of vertically related markets has shown that vertical integration can be anti-competitive because the integrated firm may harm competitors by degrading input quality (Armstrong and Sappington 2007) or by exaggerating its cost to provide access (Vickers 1995).

Vertical integration can, however, lead to greater downstream output and higher welfare than would vertical separation, to a reduction in total fixed costs due to less entry in the downstream market, to more coordination between investments in the upstream and downstream markets (Vickers 1995), and to efficiency gains from economies of scope (Kwoka 2002). This literature has focused on the effect of access price regulation and vertical integration when the regulated firm holds private cost

[3] State aid may be granted in "white areas": where NGA networks do not exist and where they are not likely to be built in the near future by private investors. Local and municipal governments are also getting directly involved in the deployment of next generation core and access networks via public-private partnerships arrangements. These municipally sponsored projects are springing up also across the United States.

information. We focus instead on the acquisition and transmission of costly demand information.

Our paper is also related to the literature that studies information acquisition on demand in unregulated markets and to the literature that analyzes the design of regulatory mechanisms in the presence of information acquisition problems.

With regard to the first strand, Hauk and Hurkens (2000) discuss information acquisition in unregulated Cournot markets. Hurkens and Vulkan (2001) study information gathering by potential entrants, whilst Dimitrova and Schlee (2003) analyze how entry affects the incentives of the incumbent to acquire information on demand. We contribute to this literature by studying the impact of regulation. With regard to the second strand of literature, see for example Cremer et al. (1998) for the case of optimal regulation and Iossa and Stroffolini (2002) for the case of price-cap regulation.

Demand information is considered in Caillaud and Tirole (2004). They study the optimal market structure when an incumbent operator has private information about market profitability and public subsidies are not allowed to finance investment in infrastructure. At the optimum, the incumbent's information is not used to determine market structure and underinvestment arises. This is in line with our result that demand information is not used to set access prices. Dobbs (2004) also shows that demand uncertainty generates underinvestment, though he focuses on price cap-regulation.

4 The Model

The industry is characterized by an upstream regulated natural monopoly and a downstream unregulated market with Cournot competition, homogenous products, and demand uncertainty. Downstream production 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 the monopolist is excluded. To obtain sharp predictions, we let the number of firms in the downstream market be fixed and equal to two in both industrial structures; only one firm—in addition to the upstream monopolist—owns the technology that is required to produce the output. [4]

Further, we assume that the upstream monopolist and its rival are equally efficient in the downstream market, and we normalize to zero the marginal cost of production. Thus the difference between the two industrial structures is solely that under S the downstream firm that was a subsidiary of the upstream monopolist is now an independent firm.

The upstream market has a marginal cost of production c_0, and a fixed investment cost C of building the infrastructure.[5] The upstream monopolist is regulated through

[4] Thus we disregard here the issue of entry. See Vareda (2010) for a study of the impact of access regulation on an entrant's decision whether to invest in a network or ask for access when the regulator cannot observe its potential demand. We also disregard incentives to invest in network quality of competing operators (for telecommunications; see, for example, Valletti and Cambini 2005).

[5] For simplicity we assume away capacity issues. The size of the infrastructure does not vary with the downstream output.

an access price a paid to it by the firm(s) in the downstream market for the use of the essential input. No monetary transfers from the government to the firm are available. We relax this assumption in Sect. 7.

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 random variable with density function $f(\theta)$ and distribution function $F(\theta)$ that satisfies: $\frac{\partial}{\partial\theta}\frac{1-F(\theta)}{f(\theta)} \leq 0$. $f(\theta)$ and $F(\theta)$ are common knowledge. ε is a random error with zero mean. 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 that are 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. We assume that the demand level θ can be privately observed at some cost only by the firms that operate in the market; information acquisition is prohibitively costly for the regulator.

For simplicity, we let the cost of acquiring information be the same across firms and we denote it by K. Whether a firm acquires information by investing K is observable but not verifiable;[6] the upstream monopolist chooses whether to acquire demand information before building the infrastructure. The downstream firms choose whether to acquire demand information before choosing their output. K captures the maturity of the market. For new services, as in the NGA example, K is high; for mature markets where a lot of past information is available, K is low. The regulator knows K, the quantities, and the final price; but the regulator cannot infer θ because of the noise ε.

We focus on direct truthful mechanisms where the access price $a^i(\hat{\theta})$, $i = I, S$, is non-negative and is set as a function of the report $\hat{\theta}$ made by the regulated upstream monopolist. We assume that both the regulatory mechanism and the report $\hat{\theta}$ are public information.[7] As the downstream firms are unregulated their information remains private.

Consider now the payoff of the firms, net of the information-acquisition cost. Profits in the upstream market are given by

$$\pi_0 = (a - c_0)\, Q, \tag{1}$$

where $Q = q_1 + q_2$ is the industry output and q_i is the quantity that is produced by each firm in the downstream market. Profits in the downstream market are[8]

$$\pi_i = (\theta - q_1 - q_2 - a)q_i \quad i = 1, 2. \tag{2}$$

Thus, the upstream monopolist maximizes

$$\Pi^i \equiv \pi_0 + \beta\pi_1 = (a - c_0)Q + \beta(\theta - Q - a)q_1 \quad i = I, S, \tag{3}$$

where β is a dummy variable with $\beta = 0$ under S and $\beta = 1$ under I.

[6] This assumption allows us to simplify the setting and avoid multiple equilibria where only one firm acquires information, but this can be either firm 1 or firm 2.

[7] This is realistic given the lack of control over the activities of regulators otherwise.

[8] In the rest of this paper $\pi_i(.)$ indicates the expected profit with respect to ε.

Under full information on θ, the Cournot equilibrium in the downstream market is characterized by:

$$q_i(\theta, c_i, c_j) = \frac{\theta + c_j - 2c_i}{3}; \quad Q(\theta, c_1, a) = \frac{2\theta - c_1 - a}{3}, \quad i = 1, 2, \tag{4}$$

where, under S, both downstream firms pay the access price so that $c_1 = c_2 = a$. Under I, the access charge is only an internal transfer for the monopolist, and thus $c_1 = c_0$ whilst $c_2 = a$. Absent information on θ, the firms set their output so as to maximize their expected profits. Because of the linearity of the demand function, Cournot equilibrium output is set on the basis of θ_0, the mean of the demand distribution.

The regulator maximizes welfare, given by profits and consumer surplus, $S(\theta, Q) = \theta Q - \frac{Q^2}{2}$, net of the information acquisition cost (if any):

$$W = (\theta - c_0)\, Q - \frac{Q^2}{2} - C - k. \tag{5}$$

where $k \in \{0, K, 2K, 3K\}$ is the total cost of information acquisition (which depends on how many firms acquire information).

The timing of the game is the following: (1) Nature chooses θ; (2) the regulator announces the regulatory mechanism; (3) the upstream monopolist decides whether to acquire information privately on θ, and he observes θ if he does; (4) based on his information, the upstream monopolist decides whether to incur C to build the infrastructure; and (5) the firms operating downstream simultaneously decide whether to acquire information privately on θ; based on their information, they choose their quantities and pay the access price. For simplicity there is no discounting.

In what follows, we start assuming that incurring C to build the infrastructure is socially valuable for all demand levels. In Sect. 8 we extend the analysis to the case where incurring C is only worthwhile for high demand realizations.

5 Benchmark: Costly Public Demand Information

As a benchmark, consider the case where demand information is public: once acquired, it is common knowledge. In this case the regulator's problem is to choose the access price $a^i(\theta) \geq 0$ that solves the following program

$$\max_{a^i(\theta)} W(\theta, a) \tag{P1}$$

$$\text{s.t.}: E\Pi^i(\theta, a) - C - K \geq 0, \tag{IR-IA}$$

$$\Pi^i(\theta, a) - C \geq 0 \text{ for all } \theta, \tag{IR}$$

where $W(\theta, a)$ and $\Pi^i(\theta, a)$ denote the welfare and the upstream monopolist's profit function after substituting for the Cournot equilibrium quantities that are given by expression (4). Constraint (IR-IA) ensures that the expected profit of the upstream monopolist covers the fixed cost of information acquisition and of building the infrastructure; constraint (IR) ensures that the monopolist will be willing to build the infrastructure once the monopolist has learned the demand level. The following Proposition is then obtained:

Proposition 1 *Under costly public information, in the absence of monetary transfers: (i) The optimal access price is decreasing in the demand level. (ii) Integration yields greater welfare than does Separation for all demand realizations.*

As a higher access price reduces industry output and thus welfare, the optimal access price level just ensures coverage of the fixed costs of building the infrastructure and acquiring information.

Under S, the monopolist can cover these costs only through the access profits; under I the monopolist can also use the profits from selling the output in the downstream market. Thus, a lower level of a can be set under I.[9] Since both access profits and downstream profits are increasing in the demand level, the access price can be lowered when demand is higher. This explains part (i).

Part (ii) stems from the industry output's being higher under I than under S. Under S, the access price is set above the marginal cost in order to cover the fixed costs of building the infrastructure and acquiring information. This creates a double marginalization problem that reduces industry output. Under I, the problem is less severe because the access price is lower and because the integrated firm does not have to pay for access, since the access price is just an internal transfer.

In this benchmark, information on demand is valuable in the downstream market as it helps the firms to adjust their output to the demand level. Instead, it is not valuable in the upstream market since the size of the infrastructure does not vary with the demand realization and building the infrastructure is always valuable. Information on demand is valuable to the regulator to set demand-based access prices that avoid excessive profits for the upstream monopolist and help to secure higher outputs. Finally, demand information costs K, and there is no duplication of information acquisition costs.

6 Private Demand Information

In this section we consider the case where the information acquired by a firm is private.

6.1 Integration

One important difference between the incentives to acquire information of the upstream monopolist and of a downstream firm is that the former is regulated whilst the latter is not. The regulated monopolist can try to use its information to affect the regulatory mechanism to its advantage, but it may also have its information used by the regulator to set less favourable regulatory rules.

The information that is reported by the monopolist is also transmitted to its rival through the public nature of the regulatory mechanism, and may therefore be used by

[9] The monopolist's profit is increasing in the access price when this is below the profit-maximizing level.

this firm to adjust its output in the downstream market. This information externality affects the value of information for the monopolist compared to a downstream firm, whose information remains private.

In particular, consider the effect of information transmission on the rival's choice of output. Anticipating that in equilibrium $\hat{\theta} = \theta$, the rival will choose the level of output that maximizes $\pi_2(\hat{\theta}, a^I(\hat{\theta})) = (\hat{\theta} - q_1 - q_2 - a^I(\hat{\theta}))q_2$. This gives: $q_2(\hat{\theta}, a^I(\hat{\theta})) = \frac{\hat{\theta} - 2a^I(\hat{\theta}) + c_0}{3}$: the rival responds to a higher demand level reported by the monopolist by expanding its output, ceteris paribus.

There is also an indirect effect through the access price. If the access price is demand-based, any change in reported demand that increases the access price will decrease the rival's output, ceteris paribus.

Anticipating this information externality, the monopolist's profit for any $\hat{\theta}$ is

$$\begin{aligned}\Pi^I\left(\theta, \hat{\theta}, a^I\left(\hat{\theta}\right)\right) &= \pi_0\left(a^I(\hat{\theta}), q_2\left(\hat{\theta}, a^I\left(\hat{\theta}\right)\right)\right) \\ &\quad + \pi_1\left(\theta, q_2\left(\hat{\theta}, a^I\left(\hat{\theta}\right)\right), q_1\left(\theta, q_2\left(\hat{\theta}, a^I\left(\hat{\theta}\right)\right)\right)\right), \end{aligned} \tag{6}$$

where $q_1(\theta, q_2(\hat{\theta}, a^I(\hat{\theta}))) = \frac{\theta - c_0 - q_2(\hat{\theta}, a^I(\hat{\theta}))}{2}$; that is, $q_1(\theta, q_2(\hat{\theta}, a^I(\hat{\theta}))) = \frac{\theta}{2} - \frac{\hat{\theta}}{6} + \frac{a^I(\hat{\theta}) - 2c_0}{3}$. Using standard techniques, the value of information for the monopolist when the information is transmitted to the rival is then[10]

$$E\Pi^I(\theta, \hat{\theta}, a^I(\hat{\theta})) - \Pi^I\left(\theta_0, a^I(\theta_0)\right) = \frac{\partial^2 \pi_1(.)}{\partial \theta^2} \frac{\sigma^2}{2} + \frac{\partial^2 \pi_1(.)}{\partial \hat{\theta} \partial \theta} \frac{\sigma^2}{2}, \tag{7}$$

where the first term is given by

$$\begin{aligned}\frac{\partial^2 \pi_1(.)}{\partial \theta^2} \frac{\sigma^2}{2} &= \frac{\partial q_1\left(\theta, q_2\left(\hat{\theta}, a^I\left(\hat{\theta}\right)\right)\right)}{\partial \theta} \frac{\sigma^2}{2}, \\ &= \frac{\sigma^2}{4}. \end{aligned} \tag{8}$$

[10] It follows from taking expectation of the second order Taylor expansion of $\Pi^I(\theta, \hat{\theta}(\theta), a^I(\hat{\theta}(\theta)))$ around $\Pi^I(\theta_0, \hat{\theta}(\theta_0), a^I(\hat{\theta}(\theta_0)))$, taking into account that an uniformed firm will choose $\hat{\theta}$ to maximize $E\Pi^I(\theta, \hat{\theta}, a^I(\hat{\theta}))$ leading to $\hat{\theta} = \theta_0$ and $argmax_{\hat{\theta}} E\Pi^I(\theta, \hat{\theta}, a^I(\hat{\theta})) = \Pi^I(\theta_0, \theta_0, a^I(\theta_0))$. We then obtain

$$E\Pi^I\left(\theta, \hat{\theta}(\theta), a^I\left(\hat{\theta}(\theta)\right)\right) = \Pi^I\left(\theta_0, \theta_0, a^I(\theta_0)\right) + \left.\frac{\partial^2 \Pi^I\left(\theta, \hat{\theta}(\theta), a^I\left(\hat{\theta}(\theta)\right)\right)}{\partial \theta^2}\right|_{\theta=\theta_0} \frac{E(\theta - \theta_0)^2}{2}.$$

where the second term of the right hand side is equal to

$$\left.\frac{\partial^2 \pi_1\left(\theta, \hat{\theta}(\theta), a^I\left(\hat{\theta}(\theta)\right)\right)}{\partial \theta^2}\right|_{\theta=\theta_0} \frac{E(\theta - \theta_0)^2}{2} + \left.\frac{\partial \pi_1\left(\theta, \hat{\theta}(\theta), a^I\left(\hat{\theta}(\theta)\right)\right)}{\partial \hat{\theta} \partial \theta}\right|_{\theta=\theta_0} \frac{E(\theta - \theta_0)^2}{2}.$$

This first term in (7) captures the profitability for the monopolist of adjusting its own downstream output to the demand level. The second term in (7) captures the informational externality that is generated by the transmission of information to the rival, through the direct effect of $\widehat{\theta}$ and through the effect of $\widehat{\theta}$ on the access price $a^I(\hat{\theta})$. This second term is given by

$$\frac{\partial^2 \pi_1(.)}{\partial \hat{\theta} \partial \theta} = \frac{\partial q_1\left(\theta, q_2\left(\hat{\theta}, a^I\left(\hat{\theta}\right)\right)\right)}{\partial \hat{\theta}}, \quad (9)$$
$$= \frac{\partial q_1}{\partial q_2}\left(\frac{dq_2}{d\hat{\theta}} + \frac{dq_2}{da^I}\frac{da^I}{d\hat{\theta}}\right).$$

Consider now the incentives of the rival to acquire information. If the monopolist is informed and reveals his information through the truthful direct regulatory mechanism, the rival learns θ without incurring K . Observing that the monopolist is informed, the rival will therefore not invest in information acquisition. If instead the monopolist is uninformed, the value of information for the rival is given by

$$E\pi_2\left(\theta, q_1(\theta_0), a\right) - \pi_2(\theta_0) = \frac{\partial^2 \pi_2\left(\theta, q_1(\theta_0), a\right)}{\partial \theta^2}\frac{\sigma^2}{2}, \quad (10)$$
$$= \frac{\partial q_2\left(\theta, q_1(\theta_0), a\right)}{\partial \theta}\frac{\sigma^2}{2},$$
$$= \frac{\sigma^2}{4},$$

where $E\pi_2\left(\theta, q_1\left(\theta_0\right), a\right)$ is the expected profit of the rival when it produces $q_2\left(\theta, q_1(\theta_0), a\right) = \frac{\theta - a - q_1(\theta_0)}{2}$. For $K \leq \frac{\sigma^2}{4}$, the rival will acquire the information.

Finally, consider the value of information for the rival when the monopolist is informed but there is no information transmission. This coincides with the value of information for the monopolist when the rival is informed, since the information externality plays no role. Such value of information is given by

$$E\pi_i\left(\theta, q_j\left(\theta\right), a\right) - \pi_i(\theta_0) = \frac{\partial^2 \pi_i\left(\theta, q_j(\theta)\right)}{\partial \theta^2}\frac{\sigma^2}{2}, \quad (11)$$
$$= \frac{\partial q_i}{\partial \theta}\left(1 - \frac{\partial q_j}{\partial \theta}\right)\frac{\sigma^2}{2},$$
$$= \frac{\sigma^2}{9},$$

where $\frac{\partial q_i}{\partial \theta}$ is derived from expression (4). As a firm anticipates that its rival will adjust its output to the demand level, and this limits its own output adjustment, the value for a firm of adjusting its downstream output to the demand information is lower when the rival is informed than when it is uninformed. [11] This explains why (11) is lower than (10).

[11] This is in line with the well-known result of the literature on information sharing. Sharing information about a common value under Cournot competition increases the correlation of firms' strategies, which reduces expected profits; see Raith (1996) for a comprehensive review.

From (7, 8, 10, 11), the difference between the incentives of the monopolist and of the rival is only given by the information externality in (9), since the effect of information on the downstream output is the same for both firms: $\frac{\partial^2\pi_1(.)}{\partial\theta^2} = \frac{\partial^2\pi_2(.)}{\partial\theta^2}$. In particular, when overall the rival's output increases with $\hat{\theta}$, the informational externality is negative and the value of information for the upstream monopolist is lower than that of its rival.

Conversely, when the rival's output decreases with $\widehat{\theta}$, the information externality is positive and the value of information for the upstream monopolist is greater than that of its rival. Since the sign of the information externality depends on the properties of the access price regulation (still from expression 9), it becomes critical to derive the optimal access price schedule.

Using standard techniques, we obtain the following Proposition:

Proposition 2 *Under Integration and costly private information, access price regulation is characterized by access price levels that are independent of the realized level of demand.*

For the access price to reflect demand conditions, the monopolist must be willing to acquire and truthfully report its demand information. But with the access price as the sole regulatory instrument, no transmission of truthful information will occur in equilibrium. Demand-based access prices are infeasible.

Intuitively, when the monopolist reports a high demand level, the quantity produced by the downstream rival increases, for any given level of a. This generates two opposite effects on the upstream firm's profits.

On the one hand, it increases access profits π_0, as more access services are sold to the rival.

On the other hand, it decreases downstream profit π_1, as the final price is lower.[12] For truthful demand reporting to be feasible, it is necessary that these two effects compensate one another at $\hat{\theta} = \theta$. But when the access price level is the only regulatory instrument, either one or the other effect prevails.

In particular, the effect on the access profit π_0 depends only on the report $\hat{\theta}$, since neither a nor q_2 depend on θ. Instead, the effect on the downstream profit π_1 depends linearly on both the true level of θ, through q_1, and the reported level $\hat{\theta}$, through q_2, and the variation in downstream profit when $\hat{\theta}$ changes depends in itself on the true realized level of θ.[13] As $\hat{\theta}$ changes, it is then impossible that these two effects compensate each other exactly at $\hat{\theta} = \theta$.

The implication of Proposition 2 is that the information externality in expression (9) is nil: Regulation plays no role on the incentives to acquire information. The value of information for the upstream monopolist is only given by its own output adjustment in the downstream market. From expressions (8, 10), and (11), this value is the same as for the rival downstream firm.

Letting $\underline{K} = \frac{\sigma^2}{9}$ and $\overline{K} = \frac{\sigma^2}{4}$, the following Corollary is then obtained:

[12] It is easy to show that for any report $\hat{\theta}$ and access price a, outputs are $q_1 = \frac{\theta - q_2(\hat{\theta}) - c_0}{2}$ and $q_2 = \frac{\hat{\theta} - 2a + c_0}{3}$.

[13] The effect of a change in q_2 on π_1 does indeed change with the demand level θ.

Corollary 1 *Under Integration and costly private information: (i) In markets where demand can be forecasted at low costs ($K \leq \underline{K}$), both firms acquire information; for higher information acquisition costs $\left(K \in \left(\underline{K}; \overline{K}\right]\right)$, only the upstream monopolist acquires information. In new markets where little demand information is available and forecasting demand is particularly complex ($K > \overline{K}$), no information acquisition takes place.*
(ii) For $K \leq \overline{K}$, the access price must ensure the regulated firm's participation for all demand realizations, whilst for $K > \overline{K}$, it needs to ensure the regulated firm's participation only in expectation.

Part (i) follows from the value of information for a firm to decrease when the other firm also acquires information compared to the case where the rival remains uninformed, as suggested by expressions (10) and (11). Only the upstream monopolist acquires information when $K \in \left(\underline{K}; \overline{K}\right]$ since it has a first mover advantage.

To explain part (ii) note that the profit of the upstream monopolist is increasing in the demand level. Inducing an informed monopolist (the case of $K \leq \overline{K}$) to invest in the infrastructure then requires the access price to be sufficiently high to cover the fixed cost of investment at the lowest demand realization. When instead the monopolist remains uninformed (the case of $K > \overline{K}$), the access price needs to ensure participation only in expected terms.

Compared to the benchmark case of costly public information two inefficiencies arise. First, no demand-based access regulation is implemented because of the absence of information transmission between the regulator and the regulated firm.

Second, duplication of information acquisition costs occurs in equilibrium for $K \leq \underline{K}$, due to the absence of information transmission between the firms in the market, which the regulatory mechanism could have in principle facilitated.

6.2 Separation

Following the same reasoning as under I, consider the game played in the downstream market under S when the level of demand reported by the upstream monopolist is $\hat{\theta}$. A downstream firm chooses q_i so as to maximize $\pi_i(\hat{\theta}) = (\hat{\theta} - q_i - q_j - a^S(\hat{\theta}))q_i$, yielding $q_i(\hat{\theta}) = \frac{\hat{\theta} - a^S(\hat{\theta})}{3}$, and therefore the profit of the upstream monopolist is equal to

$$\pi_0\left(\hat{\theta}\right) = \left(a^S\left(\hat{\theta}\right) - c_0\right) 2q_i\left(\hat{\theta}\right).$$

The upstream monopolist then has no incentive to acquire information because his profit is independent of the demand level: $\frac{\partial \pi_0(\hat{\theta}))}{\partial \theta} = 0$. The access profit π_0 only depends on the quantities produced by the downstream firms, and these are chosen on the basis of the reported realization of demand, not of its true value. [14] We then obtain the following Proposition:

[14] This result is in line with Iossa and Legros (2004) who consider a regulated monopoly and show that property rights on the firm's asset increase incentives to acquire information.

Proposition 3 *Under Separation and costly private information: (i) The regulated upstream monopolist does not acquire demand information. (ii) The access price is independent of the realized level of demand, and it is set to ensure the regulated firm's participation only in expectation.*

Part (i) follows from the discussion above; part (ii) follows immediately from part (i). The following Corollary is then obtained:

Corollary 2 *Under S, in markets where demand can be forecasted at low costs ($K \leq \underline{K}$), both downstream firms acquire information while for higher information acquisition costs, $K \in \left(\underline{K}; \overline{K}\right]$, only one downstream firm acquires information. In new markets where little demand information is available and forecasting demand is particularly complex, $K > \overline{K}$, there is no information acquisition.*

The incentives to acquire information for the downstream firms stem from the possibility to adjust their downstream output to the demand realization. Since downstream firms are identical, these incentives are the same for both firms.

Further, since the output adjustment to the demand level is independent of the level of the access price, the value of information for the two downstream firms is the same as the value of information for the firms under I. The threshold levels $\underline{K}$, $\overline{K}$ are therefore the same as under I, as, with a little abuse of notation, can be inferred from equations (10) and (11). As the value of information for a firm decreases when the other firm also acquires information, an asymmetric equilibrium arises for $K \in \left(\underline{K}; \overline{K}\right]$, where only one firm acquires information (which one is irrelevant to our purpose).

6.3 Comparison

We have seen that under both I and S the optimal access price is independent of the level of realized demand. Under I, this is because the regulator is unable to extract the information that may be acquired by the upstream monopolist, while under S it is because the regulated monopolist remains uninformed. Compared to the benchmark, the unobservability of information acquisition generates a welfare loss under both I and S, but the extent of this welfare loss differs between the two industry structures. The following Proposition summarizes our main result:

Proposition 4 *In the absence of monetary transfers, Integration yields a higher expected welfare than does Separation in new markets where little demand information is available (i.e. $K > \overline{K}$), or in mature markets where it is available (i.e. $K \leq \overline{K}$) and the fixed infrastructure cost is relatively low. Separation may instead be preferred from a welfare perspective in mature markets ($K \leq \overline{K}$) when infrastructure costs are relatively high.*

When monetary transfers cannot be used to regulate access in network industries, inducing the regulated firm to acquire and truthfully transmit information on demand is impossible. Demand information, if acquired, remains private.

Under I, this private information makes it harder to regulate the industry since, ceteris paribus, it translates into a higher access price and a rent for the firm.

The firm's participation constraint (IR) must now hold for each demand level, not just in expectation.

But under I, it is also the case that downstream profits can contribute to the coverage of the fixed cost and the cost of providing access. When the fixed cost C is low, this effect is sufficiently strong, the access price remains lower than under I despite the informative rent. We show in the Appendix that this occurs for $C \leq \bar{C}$ if $K \in (\underline{K}, \overline{K}]$, and for $C \leq \tilde{C}$, if $K \leq \underline{K}$, and that these thresholds are lower the less right-skewed the demand distribution function (i.e., the lower is $\theta_0 - \underline{\theta}$ compared to σ^2).

When instead the cost is high, that is for $C > \bar{C}$ if $K \in (\underline{K}, \overline{K}]$, and for $C > \tilde{C}$ when $K \leq \underline{K}$, ensuring the firm's participation for all demand levels under I causes the access price to be higher than under S, making welfare higher when the monopolist is not integrated downstream.

For $K > \overline{K}$, no information acquisition takes place under either industry structure. I then yields higher welfare since the monopolist's downstream profit helps to cover the fixed costs and the cost of providing access, thus allowing for a lower access price.

7 Information Transmission with Public Transfers

In this section we briefly investigate the case where public transfers are allowed. Let λ denote the shadow cost of public funds and T the transfer paid to the upstream monopolist. The profit function of the upstream monopolist is now $\pi_0 + \beta\pi_1 + T$, whilst the objective function of the regulator is $W - \lambda T$. Using standard techniques, the following Proposition is obtained:

Proposition 5 *Under costly public information with public transfers, expected welfare is higher under Integration than under Separation.*

Compared to S, the downstream profit of the integrated firm under I eases its participation constraint, making a lower access price feasible for any given level of public transfer. The industry output is then higher under I than under S for the same reasons as in the benchmark case where no public transfers are allowed.

Consider now the case where information is private. We focus on truthful direct mechanisms, $\left\{a(\hat{\theta}), T(\hat{\theta})\right\}$, specifying a and T as function of the report $\hat{\theta}$ made by the monopolist. As before, we consider the case where the regulatory mechanism and the report $\hat{\theta}$ made by the monopolist are public information.[15] The following Proposition is then obtained:

Proposition 6 *With public transfers as an additional regulatory instrument, eliciting the regulated firm's information becomes possible under Integration, whilst it remains infeasible under Separation.*
However, eliciting demand information under Integration is so costly that for $K \leq \underline{K}$ a pooling mechanism remains preferable under Integration for sufficiently low information acquisition cost (low K), for sufficiently high values of the shadow cost of

[15] As shown by Bester and Strausz (2001), the optimal direct mechanism may not be truthful, when the report of the monopolist directly affects its own payoff. This occurs in our setting through the impact of $\hat{\theta}$ on the rival's output.

public funds (high λ) or when the demand distribution is sufficiently right-skewed ($\theta_0 - \underline{\theta}$ is high compared to σ^2).
For $K \in (\underline{K}; \overline{K}]$, the pooling mechanism is preferable for any demand distributions and any value of the shadow cost.

With monetary transfers as a regulatory instrument, the regulator is able to elicit the upstream monopolist's information by adjusting the transfer t to the report $\hat{\theta}$. The best truthful direct mechanism makes the rival's quantity nonresponsive to $\hat{\theta}$ by raising the access price as higher demand levels are reported. The positive direct effect of a greater $\hat{\theta}$ on the rival's output (the first term in the bracket in expression (9)—the presence of transfers does not affect the expression—) is then compensated by the indirect negative effect generated by the greater cost of access (the second term in the bracket).

But as the rival's output is made insensitive to $\hat{\theta}$, one potential benefit of eliciting the monopolist's demand information is forgone. The demand information of the monopolist is not used by the rival to adjust its output to the demand level and allocative efficiency decreases. Furthermore, with the access price increasing in the demand level, the informative rent of the monopolist due to its private information rises substantially as demand increases.

On the other hand, a pooling mechanism, where the access price is insensitive to the demand realization, results in a lower access price and a lower firm's profit compared to the revelation mechanism above, but it implies a duplication of the information acquisition cost K when $K \leq \underline{K}$ (as both firms acquire information over this range, as in Corollary 1).

Within this range of K, a pooling mechanism is then preferable to a revelation mechanism for sufficiently low information acquisition cost K, for low shadow cost of public funds (λ), and for sufficiently right-skewed demand distributions (i.e. high $\theta_0 - \underline{\theta}$ compared to σ^2). The lower is K, the lower is the cost of the duplication of information acquisition costs; the greater is λ, the greater is the social cost of the informative rent under the revelation mechanism; and the more right-skewed is the demand distribution, the higher is the welfare gain due to the lower access price under pooling.

Instead for $K \in (\underline{K}; \overline{K}]$, where there is no duplication of information acquisition cost, the pooling mechanism is found to be preferable for any demand distribution and value of the shadow cost.

8 Infrastructure Investment

We have so far assumed that production is socially valuable for all demand realizations. Suppose now that demand information can affect the decision as to whether to invest in the infrastructure, with production's being profitable only for high demand levels. In particular, let $(\theta_0 - c_0)^2 < 4C$, which implies that downstream production is unprofitable when the firm is uninformed.[16]

[16] Recall that with linear demand the expected profit of an uninformed downstream firm coincides with the profit of an informed firm at θ_0.

Assume again that no public funds can be used to subsidize the regulated firm and that the regulator can commit to an access price policy before the infrastructure investment takes place. Let $\tilde{\theta}^i(a, C)$ denote the lowest level of θ such that production is optimal; that is, $\tilde{\theta}^i$ solves: $\Pi^i(\tilde{\theta}^i, a) = C$, for $i = I, S$. Only for $\theta \geq \tilde{\theta}^i$, where $\tilde{\theta}^i > \theta_0$, will the monopolist invest C in building the infrastructure.

For a given access price a and fixed cost C, the upstream monopolist will now acquire demand information if the following condition holds:

$$\int_{\tilde{\theta}^i(a,C)}^{\overline{\theta}} \left[\Pi^i(\theta, a) - C\right] dF(\theta) \geq K.$$

That is, the monopolist acquires information if the expected gain when demand realizations are higher than $\tilde{\theta}^i(a, C)$ exceed the cost of acquiring information. If the above condition is not met, then the upstream monopolist does not acquire information; and, as a consequence, it will not build the infrastructure.

Suppose now that the upstream monopolist has information on the demand level. Will this information be transmitted to the regulator and used to set the access price? A repetition of our earlier analysis suggests that the answer is negative.

Under I, the access price will again be independent of the demand realization since incentive compatibility conditions are independent of the support of θ, which is the only thing that has changed in the current setting.

The same will hold under S, where the independence of the monopolist's access profit to θ, makes revelation of demand information a cheap-talk, $\frac{d\pi_0(\hat{\theta})}{d\theta} = 0$. With access prices independent of demand realizations, I will then yield greater welfare than S since the downstream profit of the upstream monopolist boosts its investment incentives ($\Pi^I(\theta, a) \geq \Pi^S(\theta, a)$ leads to $\tilde{\theta}^S(a) > \tilde{\theta}^I(a)$), and it can be used to cover the cost of providing access. This yields a lower access price under I than under S for any given $\tilde{\theta}^i$.[17]

9 Conclusion

We have investigated the possibility to use demand-based access prices: access prices that are sensitive to realized demand levels, and the design of the industry structure as a means to incentivize investment when infrastructure costs are high and there is significant demand uncertainty.

We have shown that, if the demand information is costly and private and no public transfers are used, the regulator cannot elicit demand information from the regulated firm, which makes demand-based access prices infeasible. Allowing the upstream monopolist to operate downstream, as under vertical integration, may then be the best means to incentivize investment and lower access prices, although we have shown that conditions also exist for vertical separation to be preferable.

[17] Formally, it suffices to notice that for $\theta \geq \tilde{\theta}^S$ any access price that is feasible under S is also feasible under I. The downstream profit of the monopolist eases its participation constraint.

Our analysis has also investigated whether the demand uncertainty that characterizes these new technological innovations may have increased the role of the public sector in promoting efficient investments and competition, as suggested at the EU level (EU 2009). We have shown that the use of public transfers to regulate the upstream monopolist may help to implement demand-based access prices but the cost of eliciting demand information can be so high as to make this policy suboptimal.

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Appendix

Proof of Proposition 1. (i) Denoting by ν and μ the Lagrangian multipliers that are associated with the (IR-IA) and (IR) constraints, the FOC w.r.t. a is

$$\frac{dL}{da} = W_a(\theta, a) + \mu \Pi_a^i(\theta, a) + \nu \int_{\underline{\theta}}^{\overline{\theta}} \Pi_a^i(\theta, a)\, dF(\theta) = 0. \tag{12}$$

We prove first that $\nu > 0$. Suppose by contradiction that (IR-IA) is slack. Then for some θ, it must be that $\Pi^i(\theta, a) > C$ and, since $W_a < 0$, the regulator could reduce a, increase $W(\theta, a)$ and still satisfy (IR) and (IR-IA). We prove now that $\frac{da}{d\theta} < 0$. Suppose by contradiction that $\frac{da}{d\theta} \geq 0$ for some $\theta \in [\theta_1, \theta_2]$. Since $\Pi_a^i, \Pi_\theta^i > 0$, it must be that $\Pi^i(\theta, a) > C$ and $\mu = 0$ over this range. From (12), $\frac{da}{d\theta} = \frac{W_{a\theta}(\theta,a)}{-W_{aa}(\theta, Q(a,\theta))} < 0$ since $W_{a\theta}, W_{aa} < 0$, and we have a contradiction. (ii) Under I, $\pi_1 > 0$ implies: $\Pi^I(\theta, a) > \Pi^S(\theta, a)$ for all a and θ and $\Pi^i(\theta, a)$ is concave in a, the smallest level of a solving (IR) and (IR-IA) is higher under S than under I, that is $a^I(\theta) < a^S(\theta)$. From (4), this in turn implies $Q^I(\theta) > Q^S(\theta)$ and $W\left(\theta, Q^I(\theta)\right) > W\left(\theta, Q^S(\theta)\right)$. □

Proof of Proposition 2. Consider the output in the downstream market for any report $\hat{\theta}$ by the upstream monopolist. The monopolist, firm 1, maximizes $\Pi^I = (a - c_0) q_2 + (\theta - q_1 - q_2 - c_0) q_1$, which gives $q_1(\theta) = \frac{\theta - c_0 - q_2}{2}$; firm 2 anticipates that firm 1 will produce $\hat{q}_1 = \frac{\hat{\theta} - c_0 - q_2}{2}$ and chooses q_2 that maximizes $\pi_2 = \left(\hat{\theta} - \hat{q}_1 - q_2 - a\right) q_2$, which gives $q_2 = \frac{\hat{\theta} - a - \hat{q}_1}{2}$. Thus the equilibrium outputs are

$$q_1\left(\widehat{\theta}, \theta\right) = \frac{\theta}{2} - \frac{\hat{\theta}}{6} + \frac{1}{3}a - \frac{2}{3}c_0; \quad q_2\left(\widehat{\theta}\right) = \frac{\hat{\theta} - 2a + c_0}{3}.$$

Denote by $\Pi^I\left(\theta,\widehat{\theta}\right)$, the value function, i.e.,

$$\Pi^I\left(\theta,\widehat{\theta}\right)=\left(a^I\left(\widehat{\theta}\right)-c_0\right)q_2\left(\widehat{\theta}\right)+\left(\theta-q_1\left(\widehat{\theta},\theta\right)-q_2\left(\widehat{\theta}\right)-c_0\right)q_1\left(\widehat{\theta},\theta\right). \quad (13)$$

Following standard techniques,[18] the FOC for truth-telling is: $\left.\frac{d\Pi^I\left(\theta,\hat{\theta}\right)}{d\hat{\theta}}\right|_{\widehat{\theta}=\theta}=0$, where

$$\begin{aligned}\frac{d\Pi^I\left(\theta,\hat{\theta}\right)}{d\hat{\theta}}&=\left(a^I\left(\widehat{\theta}\right)-c_0-q_1\left(\widehat{\theta},\theta\right)\right)\frac{dq_2\left(\widehat{\theta}\right)}{d\hat{\theta}}+\frac{da^I\left(\widehat{\theta}\right)}{d\hat{\theta}}q_2\left(\widehat{\theta}\right)\\&=\frac{1}{3}\left(-\frac{\theta}{2}+\frac{\hat{\theta}}{6}+\frac{2}{3}a-\frac{1}{3}c_0\right)+\frac{da^I\left(\widehat{\theta}\right)}{d\hat{\theta}}\frac{1}{3}\left(\frac{2}{3}\hat{\theta}-\frac{10}{3}a+\theta+\frac{5}{3}c_0\right).\end{aligned}$$

Thus we have

$$\left.\frac{d\Pi^I\left(\theta,\hat{\theta}\right)}{d\hat{\theta}}\right|_{\widehat{\theta}=\theta}=0\implies-q_2(\widehat{\theta}=\theta)\left(1-5\frac{da^I(\theta)}{d\theta}\right)=0, \quad (14)$$

which, for $q_2>0$, is satisfied for $\frac{da^I(\theta)}{d\theta}=\frac{1}{5}$. The SOC require $\left.\frac{d^2\Pi^I\left(\theta,\hat{\theta}\right)}{d\hat{\theta}^2}\right|_{\widehat{\theta}=\theta}\leq 0$, where

$$\left.\frac{d^2\Pi^I\left(\theta,\hat{\theta}\right)}{d\hat{\theta}^2}\right|_{\widehat{\theta}=\theta}=\frac{1}{3}\left(\frac{1}{2}+4\frac{da^I(\theta)}{d\theta}-10\frac{da^I(\theta)}{d\theta}\frac{da^I(\theta)}{d\theta}\right). \quad (15)$$

The function $y=\frac{1}{2}+4x-10x^2$ is concave and has two roots: $-\frac{1}{10},\frac{1}{2}$. The SOC are therefore satisfied either for $\frac{da}{da}\leq-\frac{1}{10}$ or for $\frac{da}{d\theta}\geq\frac{1}{2}$. Both ranges are incompatible with the FOC in (14). □

Proof of Corollary 1. (i) From (8–11) and Proposition 2, the value of information for the monopolist and the rival is equal to $\frac{\sigma^2}{4}$ when the other firm is uninformed and $\frac{\sigma^2}{9}$ when the other firm is informed. Thus, for $K\leq\frac{\sigma^2}{9}$, both firms will acquire information.
For $K\in\left(\underline{K};\overline{K}\right]$, the monopolist who moves first will acquire information, whilst the rival will prefer not.
(ii) Since $W_a<0$, the optimal access price, a^I, is the minimum level of a satisfying (IR) and (IR-IA). From (i), for $K\leq\underline{K}$ both firms are informed, downstream outputs are given by (4) and the (IR) constraint for the monopolist requires $\Pi^I(\theta,a)\geq C$, for

[18] See Chapter 2.11.2 in Laffont and Martimort (2002).

all θ, where $\Pi^I(\theta, a) \equiv \Pi^I(q_1(\theta), q_2(\theta))$. Since $W_a < 0$ and $\Pi^I_\theta(\theta, a) > 0$, a^I is the minimum level of a satisfying: $E\Pi^I(\theta, a) \geq C + K$ and $\Pi^I(\underline{\theta}, a) \geq C$.
Thus, if we let $\hat{K}$ be such that $E\Pi^I(\theta, \underline{a}) = C + \hat{K}$ where $\underline{a}$ solves $\Pi^I(\underline{\theta}, \underline{a}) = C$, then $a^I > \underline{a}$ and (IR) is slack for all θ for $K > \hat{K}$ and $a^I = \underline{a}$ for $K \leq \hat{K}$. Notice that $\hat{K} = E\Pi^I(\theta, \underline{a}) - \Pi^I(\underline{\theta}, \underline{a})$, which, by adding and subtracting $\Pi^I(\theta_0, \underline{a})$, can be written as

$$\hat{K} = \underline{K} + \Pi^I(\theta_0, \underline{a}) - \Pi^I(\underline{\theta}, \underline{a}) > \underline{K}.$$

Therefore, for $K \leq \underline{K}$, $a^I = \underline{a}$.
Now consider the range $K \in (\underline{K}, \overline{K}]$ where only the monopolist is informed. Downstream outputs are $q_1(\theta, \theta_0) = \frac{\theta}{2} - \frac{\theta_0}{6} + \frac{1}{3}a - \frac{2}{3}c_0$ and $q_2(\theta_0) = \frac{\theta_0 - 2a + c_0}{3}$, and the (IR) constraint for the monopolist is given by $\Pi^I(\theta, \theta_0, a) \geq C$ for all θ, with $\Pi^I(\theta, \theta_0, a) \equiv \Pi^I(q_1(\theta, \theta_0), q_2(\theta_0))$. Let $\underline{\breve{a}}$ solve $\Pi^I(\underline{\theta}, \theta_0, \underline{\breve{a}}) = C$, where $\underline{\breve{a}} > \underline{a}$ since $\Pi^I(\underline{\theta}, \theta_0, a) < \Pi^I(\underline{\theta}, a)$, and let $\check{K}$ be such that $E\Pi^I(\theta, \theta_0, \underline{\breve{a}}) = C + \check{K}$. Notice that $\check{K} = E\Pi^I(\theta, \theta_0, \underline{\breve{a}}) - \Pi^I(\underline{\theta}, \theta_0, \underline{\breve{a}})$ which, by adding and subtracting $\Pi^I(\theta_0, \underline{\breve{a}})$, can be written as

$$\check{K} = \overline{K} + \Pi^I(\theta_0, \underline{\breve{a}}) - \Pi^I(\underline{\theta}, \theta_0, \underline{\breve{a}}) > \overline{K}.$$

It follows that for $K \in (\underline{K}, \overline{K}]$, the equilibrium access price is $a^I = \underline{\breve{a}} > \underline{a}$ with a discontinuity at $\underline{K}$. Finally, for $K > \overline{K}$, the monopolist is uninformed and thus $a^I = a_0$, where a_0 satisfies: $E\Pi^I(\theta, a_0) = C$, with $a_0 < \underline{a}$. There is a discontinuity around $\overline{K}$. □

Proof of Proposition 3. (i) The value of information is nil for the upstream firm since $\pi_0(\hat{\theta})$ is independent of θ. (ii) From (i) the upstream firm's participation constraint needs to be ensured only in expectation. The optimal access price, a^S, thus solves: $E\pi_0(\theta, a^S) = C$, where $E\pi_0(\theta, a^S) = (a^S - c_0)\frac{2(\theta_0 - a^S)}{3}$ regardless of whether the downstream firms are informed or not. This leads to $a^S > c_0$ for $C > 0$. □

Proof of Corollary 2. The reasoning is the same as for Corollary 1. □

Proof of Proposition 4. From (5), $W^I > W^S$ if $Q^I > Q^S$ for fixed k. From Corollary (1) and Proposition (3), the equilibrium outputs are

$$Q^I(\theta, a^I) = \frac{2\theta - a^I - c_0}{3}; \quad Q^S(\theta, a^S) = \frac{2(\theta - a^S)}{3} \text{ for } K \leq \underline{K} \tag{16}$$

$$Q^I(\theta, \theta_0, a^I) = \frac{\theta}{2} + \frac{\theta_0}{6} - \frac{a^I}{3} - \frac{c_0}{3};$$

$$Q^S(\theta, \theta_0, a^S) = \frac{\theta}{2} + \frac{\theta_0}{6} - \frac{2a^S}{3} \text{ for } K \in (\underline{K}; \overline{K}]$$

$$Q^I(\theta_0, a^I) = \frac{2\theta_0 - a^I - c_0}{3}; \quad Q^S(\theta_0, a^S) = \frac{2(\theta_0 - a^S)}{3} \text{ for } K > \overline{K}$$

Since $a^S > c_0$, a sufficient condition for $Q^I > Q^S$ is $a^S \geq a^I$. For $K > \overline{K}$, Proposition 3 implies $a^S > a^I = a_0$ since $E\pi_0(\theta, a^S) = E\Pi^I(\theta, a_0) = C$ and $E\pi_0(\theta, a) < E\Pi^I(\theta, a)$ with $E\Pi^I(\theta, a)$ increasing in a. Therefore $Q^I > Q^S$ and $W^I > W^S$.

Now suppose that $K \leq \underline{K}$. Since under both I and S, $k = 2K$, then $W^I > W^S$ if $Q^I\left(\theta, a^I\right) > Q^S\left(\theta, a^S\right)$. Let $\hat{C} \equiv \pi_1(\underline{\theta}, a = c_0)$. Then for all $C \leq \hat{C}$, $a^I \leq c_0 < a^S$ and therefore $Q^I\left(\theta, a^I\right) > Q^S\left(\theta, a^S\right)$ and $W^I\left(\theta, a^I\right) > W^S\left(\theta, a^S\right)$.

For $C \geq \hat{C}$, increases in C raise both a^I and a^S. By implicitly differentiating $\Pi^I(\underline{\theta}, \underline{a}) - C = 0$ and $E\pi_0(\theta, a^S) - C = 0$, we find respectively $\frac{da^I}{dC} = \frac{9}{5}\left(\underline{\theta} + c_0 - 2a^I\right)^{-1}$ and $\frac{da^S}{C} = \frac{3}{2}\left(\theta_0 + c_0 - 2a^S\right)^{-1}$ with $\frac{da^I}{dC} > \frac{da^S}{C}$ at $a^I = a^S$. This implies that there exists a level of $C > \hat{C}$, such that $a^I = a^S$. For some $\tilde{C}$ yet above this level, a^I is sufficiently higher than a^S that $Q^I = Q^S$ and therefore $W^I = W^S$. Since $a^S - a^I$ decreases in $\theta_0 - \underline{\theta}$, $\tilde{C}$ decreases in $\theta_0 - \underline{\theta}$.

Now consider the range of $K \in \left(\underline{K}, \overline{K}\right]$ where under both I and S we have $k = K$ and therefore $W^I > W^S$ if $Q^I > Q^S$. Let $\check{C} \equiv \pi_1(\underline{\theta}, \theta_0, a = c_0)$, where $\hat{C} > \check{C}$ since $\pi_1(\underline{\theta}, a = c_0) \equiv \pi_1(q_1\left(\underline{\theta}\right), q_{21}\left(\underline{\theta}\right), a = c_0) > \pi_1(\underline{\theta}, \theta_0, a = c_0) \equiv \pi_1(q_1\left(\underline{\theta}, \theta_0\right), q_2\left(\theta_0\right), a = c_0)$. Then for $C \leq \check{C}$, we have $a^I \leq c_0$ and therefore $a^I < a^S$ and $Q^I\left(\theta, \theta_0, a^I\right) > Q^S\left(\theta, \theta_0, a^S\right)$. For $C \geq \check{C}$, increases in C raise both a^I and a^S. Since $\frac{da^I}{dC} = \left(\frac{\underline{\theta}}{3} + \frac{2\theta_0}{9} - \frac{10a^I}{9} + \frac{5c_0}{9}\right)^{-1} > \frac{da^S}{C} = \frac{3}{2}\left(\theta_0 + c_0 - 2a^S\right)^{-1}$ at $a^I = a^S$, there exists a $C > \check{C}$, such that $a^I = a^S$. For some $\bar{C}$ yet above this level, a^I is sufficiently higher than a^S that $Q^I = Q^S$ and thus $W^I = W^S$. Since $a^S - a^I$ decreases in $\theta_0 - \underline{\theta}$, $\bar{C}$ decreases in $\theta_0 - \underline{\theta}$. □

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Proof of Proposition 5 It follows from (IR) and (IR-IA) being easier to satisfy when $\beta = 1$ instead of $\beta = 0$. □

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Proof of Proposition 6 With public transfers, the profit function of the monopolist when it reports $\widehat{\theta}$ and the true demand level is θ is given by

$$\Pi^I\left(\theta, \widehat{\theta}\right) = \left(\theta - q_1\left(\widehat{\theta}, \theta\right) - q_2\left(\widehat{\theta}\right) - c_0\right) q_1\left(\widehat{\theta}, \theta\right) + (a^I\left(\widehat{\theta}\right) - c_0) q_2\left(\widehat{\theta}\right) + T\left(\widehat{\theta}\right). \tag{17}$$

The FOC and SOC for truth-telling then require respectively

$$\left.\frac{d\Pi^I\left(\theta, \hat{\theta}\right)}{d\hat{\theta}}\right|_{\widehat{\theta}=\theta} = 0 \Longrightarrow q_2\left(\hat{\theta} = \theta\right)\left(1 - 5\frac{da}{d\hat{\theta}}\right) = \frac{dT}{d\hat{\theta}},$$

and

$$\frac{d^2\Pi^I\left(\theta, \hat{\theta}\right)}{d\hat{\theta}^2} \leq 0 \Longrightarrow \frac{da(\theta)}{d\theta} \geqslant \frac{1}{2}. \tag{18}$$

By implicitly differentiating (17), we obtain

$$\frac{d}{d\theta}\left(\frac{da}{dT}\right) = -\frac{\Pi^I_{a\theta}}{\left(\Pi^I_a\right)^2} > 0,$$

which shows that the Spence-Mirrelees condition is satisfied, and thus there exists a couple $\{a(.), T(.)\}$ that satisfy FOC and SOC. Since the rent is increasing in a and output is decreasing, the optimal truthful direct mechanism solves (18) as an equality, leading to $\frac{da(\theta)}{d\theta} = \frac{1}{2}$.

Let us now compare welfare under this truthful direct mechanism (hereafter referred to as R-mechanism and denoted by superscript R) with the welfare under the best pooling mechanism (hereafter referred to as P-mechanism and denoted by superscript P). Fix $a^P = a^R\left(\underline{\theta}\right)$ and $T^P = T^R\left(\underline{\theta}\right)$. Since $\frac{da^R(\theta)}{d\theta} = 0.5$, $a^R(\theta) = a^R(\underline{\theta}) + \int_{\underline{\theta}}^{\theta} \frac{da^R(\theta)}{d\theta} d\theta = a^R(\underline{\theta}) + \frac{(\theta - \underline{\theta})}{2}$. For $K \le \frac{\sigma^2}{9}$, the information structure is the same under the P-mechanism and the R-mechanism—namely, both downstream firms are informed—and therefore $Q^P\left(\underline{\theta}\right) = Q^R\left(\underline{\theta}\right)$. Taking the first and second derivative of welfare w.r.t θ under the R-mechanism we obtain

$$\begin{aligned}\frac{dW^R(\theta)}{d\theta} &= Q^R(\theta) + \left(\theta - Q^R(\theta)\right)\frac{dQ^R(\theta)}{d\theta}\\ &= \frac{\theta}{2} + \frac{Q^R\left(\underline{\theta}, \theta\right)}{2};\\ \frac{d^2W^R(\theta)}{d\theta^2} &= \frac{3}{4},\end{aligned}$$

since $Q^R\left(\underline{\theta}, \theta\right) = \frac{2\theta - a^R(\theta) - c_0}{3}$ which is equal to $\frac{3\theta + \underline{\theta} - 2a^R(\underline{\theta}) - 2c_0}{6}$ and since $\frac{dQ^R}{d\theta} = \frac{1}{2}$. Instead, under the P-mechanism

$$\begin{aligned}\frac{dW^P(\theta)}{d\theta} &= Q^P(\theta) + \left(\theta - Q^P(\theta)\right)\frac{dQ^P(\theta)}{d\theta}\\ &= \frac{2\theta}{3} + \frac{Q^P(\theta)}{3};\\ \frac{d^2W^P(\theta)}{d\theta^2} &= \frac{8}{9}\end{aligned}$$

since $Q^P(\theta) = \frac{2\theta - a - c_0}{3}$ and $\frac{dQ^P}{\partial\theta} = \frac{2}{3}$. Using Taylor expansion

$$\begin{aligned}EW^R(\theta, a) = EW^R\left(\underline{\theta}\right) &+ E\left|\frac{\partial W^R(\theta)}{\partial\theta} - \lambda\frac{dT^R(\theta)}{d\theta}\right|_{\theta=\underline{\theta}}\left(\theta - \underline{\theta}\right)\\ &+ E\left|\frac{\partial^2 W^R(\theta)}{\partial\theta^2} - \lambda\frac{d^2T^R}{d\theta^2}\right|_{\theta=\underline{\theta}}\frac{\left(\theta - \underline{\theta}\right)^2}{2},\end{aligned}$$

$$= W^R\left(\underline{\theta}\right) + \left|\frac{\underline{\theta}}{2} + \frac{Q^R\left(\underline{\theta}\right)}{2} - \lambda\frac{3}{2}q_2\left(\underline{\theta}\right)\right|_{\theta=\underline{\theta}}\left(\theta_0 - \underline{\theta}\right)$$
$$+\frac{3}{4}\frac{E\left(\theta-\underline{\theta}\right)^2}{2}$$

since $\frac{dT^R(\theta)}{d\theta} = \frac{3}{2}q_2$ and $\frac{d^2T}{d\theta^2} = 0$ at $da/d\theta = 0.5$. Instead

$$EW^P(\theta, a) = EW^P\left(\underline{\theta}\right) + \left|\frac{\partial W^P(\theta)}{\partial\theta}\right|_{\theta=\underline{\theta}}\left(\theta_0 - \underline{\theta}\right) + \left|\frac{\partial^2 W^P\left(\underline{\theta}\right)}{\partial\theta^2}\right|_{\theta=\underline{\theta}}\frac{E\left(\theta-\underline{\theta}\right)^2}{2},$$
$$= EW^P\left(\underline{\theta}\right) + \left(\frac{2\underline{\theta}}{3} + \frac{Q^R\left(\underline{\theta}\right)}{3}\right)\left(\theta_0 - \underline{\theta}\right) + \frac{8}{9}\frac{E\left(\theta-\underline{\theta}\right)^2}{2}$$

since $\frac{dT}{d\theta} = \frac{d^2T}{d\theta^2} = 0$. Noting that for $K \leq \frac{\sigma^2}{9}$, $EW^R\left(\underline{\theta}, a\right) - EW^P\left(\underline{\theta}, a\right) = K$, we obtain

$$\begin{aligned}
&EW^P(\theta, a) - EW^R(\theta, a) \\
&\quad = -K + \left(\frac{2\underline{\theta}}{3} + \frac{Q^R\left(\underline{\theta}\right)}{3} - \frac{\underline{\theta}}{2} - \frac{Q^R\left(\underline{\theta}\right)}{2} + \lambda\frac{3}{2}q_2\left(\underline{\theta}\right)\right)\left(\theta_0 - \underline{\theta}\right) \\
&\quad\quad + \frac{5}{36}\frac{E\left(\theta-\underline{\theta}\right)^2}{2}, \\
&\quad = \left(\frac{\underline{\theta} - Q^R\left(\underline{\theta}\right)}{6} + \lambda\frac{3}{2}q_2\left(\underline{\theta}\right)\right)\left(\theta_0 - \underline{\theta}\right) + \frac{5}{36}\frac{E\left(\theta-\underline{\theta}\right)^2}{2} - K, \\
&\quad = \left(\frac{a + \underline{\theta} + c_0}{18} + \lambda\frac{3}{2}q_2\left(\underline{\theta}\right)\right)\left(\theta_0 - \underline{\theta}\right) + \frac{5E\left(\theta-\underline{\theta}\right)^2}{72} - K,
\end{aligned} \tag{19}$$

where for $K = \frac{\sigma^2}{9}$, the last two terms in (19) are equal to

$$\frac{5\left(E\theta^2 + \underline{\theta}^2 - 2\theta_0\underline{\theta}\right) - 8\left(E\theta^2 - \theta_0^2\right)}{72},$$
$$= \frac{-3\left(E\theta^2 - \theta_0^2\right) + 5\left(\theta_0 - \underline{\theta}\right)^2}{72} \gtrless 0$$

It follows that for sufficiently high λ, low K, or high $\left(\theta_0 - \underline{\theta}\right)$ compared to σ^2, or for sufficiently low $E\left(\theta - \underline{\theta}\right)^2$, we have $EW^P(\theta, a) - EW^R(\theta, a) > 0$, which implies that for $a^P = a^R\left(\underline{\theta}\right)$ and $T^P = T^R\left(\underline{\theta}\right)$ the P-mechanism can replicate the R-mechanism. The optimal P-mechanism will therefore yield a higher welfare than the R-mechanism. □

Consider now the range $K \in \left(\frac{\sigma^2}{9}, \frac{\sigma^2}{4}\right)$, where

$$Q^R\left(\underline{\theta}, \theta\right) = \frac{3\theta + \underline{\theta} - 2a^R\left(\underline{\theta}\right) - 2c_0}{6}; \quad Q^P\left(\theta, \theta_0\right) = \frac{3\theta + \theta_0 - 2a - 2c_0}{6},$$

and therefore

$$\begin{aligned}\frac{dW^P\left(\theta, \theta_0\right)}{d\theta} &= Q^P\left(\theta, \theta_0\right) + \left(\theta - Q^P\left(\theta, \theta_0\right)\right)\frac{dQ}{\partial\theta}, \\ &= \frac{\theta}{2} + \frac{Q^P\left(\theta, \theta_0\right)}{2}; \\ \frac{d^2W^P\left(\theta, \theta_0\right)}{d\theta^2} &= \frac{3}{4}.\end{aligned}$$

whist $\frac{dW^R(\theta)}{d\theta}$ and $\frac{d^2W^R(\theta)}{d\theta^2}$ remain unchanged. We then have

$$EW^P\left(\theta, \theta_0, a\right) - EW^R\left(\theta, a\right) = \left(\frac{Q^P\left(\theta_0, \underline{\theta}\right)}{2} - \frac{Q^R\left(\underline{\theta}\right)}{2} + \lambda\frac{3}{2}q_2\left(\underline{\theta}\right)\right)\left(\theta_0 - \underline{\theta}\right) > 0.$$

Therefore over the range $K \in \left(\frac{\sigma^2}{9}, \frac{\sigma^2}{4}\right)$, the P-mechanism can replicate the R-mechanism and yield a strictly greater welfare.

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