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Abstract. If the access network is an economic bottleneck, then the regulator may consider vertical separation of the telecommunications incumbent. There is the concern that separation dilutes quality-enhancing network investment, and social welfare. We show that, despite some loss of operational coordination and potential hold-up problems, vertical separation may raise investment and welfare compared with integration. While structural more than functional separation raises investment, it is functional more than structural separation that raises welfare (due to investment cost). The results obtained shed light on the effects of different forms of separation on the incentive to build-out Next Generation Access networks (NGAs).

[1] This paper has been presented at the 24th Annual Congress of the European Economic Association in Barcelona, 23-27 August 2009. An earlier version of this paper has been presented at the Telecom ParisTech Conference on the Economics of ICT in Paris, 19–20 June 2008.

1 Introduction

This paper investigates how the vertical industry structure affects the bottleneck owner's incentives to invest in infrastructure quality, and more generally social welfare. For this purpose, we compare the relevant outcomes under three alternative scenarios of vertical integration, structural separation, and functional separation of the bottleneck owner.

We focus on fixed telecommunications[2]. The bottleneck in this industry is the wireline local access network, since replication of the incumbent's assets is generally infeasible or economically undesirable[3]. The access network owner typically is under the scrutiny of a National Regulatory Authority (NRA) that imposes behavioral remedies relative to wholesale access conditions, while preserving vertical integration in retail markets[4]. Vertical separation implies splitting the incumbent into an upstream entity managing bottleneck activities and providing wholesale access, and a downstream entity managing competitive activities (such as the long-distance backbone) and providing retail services.

We distinguish two options for vertical separation. Structural separation entails distinct ownership and control of upstream and downstream entities. Functional separation implies creating independent business units, but does not imply a change of ownership of assets (see e.g. Cave, 2006). Thus, the sole owners of the firm take strategic long-run decisions (such as network investment) in the interest of the whole company, although they cannot completely control short-run decisions (such as retail pricing).

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[2] However, the situation where a dominant firm controls the supply of an essential input, while there is potential infrastructure competition in vertically related markets, is common to network industries such as electricity, gas, and railways (where the bottleneck respectively is electricity transmission, gas transportation, and railway track). See OECD (2006) for a review on the pro-competitive effects of vertical separation in several countries.

[3] Empirical evidence shows that competitive access network roll out in Europe has been targeted at business customers or urban areas, so as there is limited replication of the incumbent's access network (COCOM, 2008). On the other hand, end-to-end infrastructure competition is more developed in other countries, such as the US.

[4] However, accounting separation has frequently been used to improve the effectiveness of behavioral remedies.

In this paper, we formally address three basic issues: i) is vertical separation of the bottleneck owner a proper remedy to promote competition under prospective deployment of new access infrastructures (the so-called Next Generation Access networks, or NGAs)?; ii) does vertical separation foster, or rather hamper investment in NGAs?; and iii) which type of separation (if any), functional or structural, produces social gains, and in which cases?

In the recent past, the benefits of separation have been deemed uncertain while the costs potentially large (see e.g. OECD, 2003). One of the rationales is that vertical separation would threaten the loss or reduction of operational coordination between upstream and downstream activities[5]. Thus, the impact on consumers in terms of reduced prices and improved service quality would be unclear, while there would be a considerable one-off cost of divestment.

However, when the access network is an enduring economic bottleneck, the vertically integrated firm has both the motivation and the means to foreclose competitors. Actually, the classic response of behavioral regulation to price and, above all, non-price discrimination is often ineffectual. Thus, the NRA should be able to treat structural competition problems by structural remedies. Under vertical separation, the NRA can effectively impose on the upstream entity the obligation to treat all downstream entities, either affiliated or unaffiliated, in a perfectly equivalent manner, thus ensuring equality of access to the bottleneck input[6].

One of the most critical issues related to mandatory separation of the integrated firm is the adverse effect this may produce on investment in network quality. Because of the incompleteness of contracts, if investment involves relationship-specific assets then vertical

[5] Vertical integration may enhance the availability of information; may exploit economies of scope; may reduce transaction costs; and may reduce the distortions associated with upstream and/or downstream market power.

[6] Structural separation has been rarely adopted in telecommunications (a notable exception being the break up of the Bell System in the US in 1984). Nonetheless, the European Commission has recently proposed to include functional separation in the set of remedies that NRAs may use to promote competition in relevant markets. Functional separation has already been employed in the UK, where the incumbent has committed to behavioral and organizational changes to provide essential wholesale services on an 'equivalence of inputs' basis.

separation potentially gives rise to hold up problems causing suboptimal investment. This adverse effect would be highly detrimental in the current phase where several incumbents worldwide have announced the build out of NGAs[7]. In fact, NGAs deliver very high bandwidths that support provision of new value-added interactive services (such as High-Definition IP-TV)[8], and may increase the productivity and competitiveness of a country.

It is worth noting that the unique characteristics of NGAs are likely to have a profound effect on competition and industry structure, thus posing new regulatory challenges. On the one hand, incumbents argue that a lenient regulatory regime is vital to maintain the economic rationale to roll out NGAs, which may impose significant costs and risks. On the other hand, prospective technology deployments raise Other Licensed Operators' (OLOs') costs and undermine the progress recently achieved in intra-platform competition through Local Loop Unbundling, or LLU (see e.g. Leporelli and Reverberi, 2003 and 2004)[9]. If there is scarce inter-platform competition, then vertical separation (with suitably regulated charges to NGAs) may be essential to prevent market foreclosure.

Our model considers the main effects of the vertical industry structure on efficiency and competition, and their impact on access regulation and investment. We assume that, in all scenarios, the NRA sets the network access charge[10], while firms compete in prices in the retail broadband access market, where there is partial participation, that is, low-willingness to pay (henceforth, wtp) consumers may not be active. Under vertical integration, the incumbent

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[7] NGAs are realized by extending the fibre network closer to the customer premises, either to the home (FTTH architecture) or to the street cabinet (FTTC architecture). NGA investment plans include mainly FTTC deployments in Europe, and mainly FTTH deployments in the US, Korea and Japan.

[8] Capacity constraints may mean that wireless networks are less suitable for such high-bandwidth applications.

[9] A number of studies estimate that sub-loop unbundling (SLU), which requires OLOs to further extend their networks compared with LLU, is not economically viable to reach the mass market (see e.g. Analysis, 2007).

[10] Thus, we assume that the NRA has no direct control over network investment. This is generally the case when the investing firm does not receive public subsidies.

has a two-fold advantage over the rival firm, which results in vertical product differentiation. First, she has a higher operational co-ordination. Second, she has a higher ability to benefit from investment in network quality and provide value-added services[11].

Under vertical separation, downstream firms attain truly equivalent access to the essential input. Thus, we assume that they gain the same demand-side spillover from investment[12]. With functional separation, the incumbent maintains some efficiencies of integration (such as operational coordination), so as to provide higher quality than the rival firm. Moreover, the upstream entity invests to maximize the whole company's profit, thus reducing hold up problems. Structural separation causes the highest efficiency loss relative to integration, but removes any downstream competitive advantage. Moreover, the access owner gains the entire profit in the upstream market and takes investment decisions on the sole basis of that profit.

We obtain that vertical separation may raise quality investment compared with vertical integration. This finding is all the more evident the more effectively separation promotes competition. Thus, in contrast to the prevailing wisdom, there is not a clear trade-off between fostering competition and ensuring investment. When there is a monopoly under integration[13], separation raises investment provided that there is a small loss of operational coordination, or the investment spillover is high. When there is a duopoly under integration, a necessary condition for separation to raise investment is that separation does not reduce market participation. This condition is also sufficient when the investment spillover is high enough.

We have a higher access charge and higher investment under structural rather than functional separation, while things are more controversial when separation is compared with

[11] Thus, the integrated firm enjoys a higher demand-side spillover from investment. This follows from premium content provision, or from non-price discrimination degrading the input quality provided to the rival firm.

[12] We also assume that, due to coordination problems, the spillover is lower than the one of the integrated firm.

[13] Despite access regulation, the integrated firm may strategically invest to foreclose the rival firm.

integration. In fact, we have that vertical separation is not always associated with a higher access charge, and that a higher charge does not always imply higher investment. The results obtained depend on the interplay between retail competitive conditions associated with vertical industry structures and access regulation.

We also obtain that vertical separation may raise welfare compared with integration. When there is a monopoly under integration, a necessary condition for either functional or structural separation to raise welfare is that it raises investment. When there is a duopoly under integration, it is only functional separation that raises welfare when the investment spillover is high enough. Albeit structural separation always encourages higher investment compared with functional separation, in the great majority of cases the gross social surplus generated by the additional investment does not offset the incremental investment cost.

This paper is organized as follows. Section 2 discusses the literature. Section 3 presents the model and compares the alternative scenarios respectively of vertical integration and separation (either functional or structural). Section 4 contains some concluding remarks.

2 Relevant literature

There is a small literature that investigates how the institutional setting affects investment in network quality. In a recent policy paper, Cave and Doyle (2007) argue that there is not evidence that vertical separation dilutes investment incentives compared with an integrated structure. Nonetheless, the results obtained in some formal papers do not support this claim.

Buehler *et al.* (2004) show that, in a chain of monopolies (possibly with competition *for* the retail market), the network owner's quality investment is generally smaller under vertical separation than integration. Buehler *et al.* (2006) allow for retail quantity competition with a homogeneous product. They show that there is a price vs. quality trade-off when opening up an integrated monopoly to competition and banning the incumbent from the retail market, since it cannot yield both a lower retail price and higher network quality. However, they do not weigh vertical integration (with downstream competition) directly against separation in terms of investment and welfare. They also do not consider the most relevant case to the retail broadband market, that is, imperfect price competition with differentiated products[14].

The same remarks hold for Cremer *et al*. (2007), which have been the first to model the scenario of functional separation ('legal unbundling') as is done in our paper[15]. They find that disallowing joint ownership of upstream and downstream facilities (as in the case of structural separation) reduces investment in network size. While their finding is a direct implication of the hold up problem, their model fails to consider the countervailing impact that structural separation has on downstream competition, and that this in turn may have on investment.

A major difference from our model is that we consider investment in network quality. Different from investment in network size, quality investment raises consumers' wtp so as to shift firms' demand curves upwards. In addition, the marginal cost of investment rises with quality while is constant with size. Hence, different from investment in size, in our model a higher investment is not necessarily associated with higher social surplus. Moreover, the access charge is not optimally regulated at cost, but depends on the vertical industry structure.

Chen and Sappington (2009) try to fill a void in the literature by recognizing that the optimal design of input pricing rules, accounting explicitly for investment incentives, should

[14] On more technical grounds, they do not assume specific demand and cost functions, but they consider only interior solutions. Conversely, we make standard assumptions, but we show that corner solutions play a major role. Moreover, they assume an exogenous access charge, while in our model the NRA sets the optimal charge.

[15] Hoeffler and Kranz (2007) assume that under legal unbundling it is the downstream affiliated unit that aims at maximizing the whole firm's profit. This assumption is less suited to deal with upstream network investment.

depend on the prevailing industry structure and on the nature of downstream competition[16]. They find that the optimal rule tends to depart more from cost under vertical integration with Cournot competition (thus fostering higher investment), and under vertical separation with Bertrand competition (but the impact on investment is less clear). Nonetheless, they consider process innovation rather than product innovation. Moreover, they do not consider the case of functional separation. Finally, they assume competition with a homogeneous product[17].

On the whole, the above papers are well suited to such network industries as energy and railways, but less suited to model broadband competition in telecoms. As we have argued, the latter requires different assumptions, which we try to consider in our model. We are thus able to reverse previous literature findings. In fact, we find that quality investment may be higher under separation than integration, and that (mostly functional) separation may raise welfare.

3 The model

An upstream firm provides wholesale access to a bottleneck (the local network) to two downstream firms *i* and *e* competing in the retail broadband access market. Downstream firms cannot bypass the local network, so as they have to buy the essential input from the upstream firm in order to provide retail services. Consequently, if downstream firms are pure service

[16] There has been wide research on static access pricing to a vertically integrated firm's network (see Armstrong, 2002), but there is a limited literature on the dynamic properties of access pricing rules (see Guthrie, 2006).

[17] In their model, the regulator maximizes consumer surplus rather than welfare. They find that the output with Cournot competition is insensitive to non-price discrimination by the vertically integrated firm. They also find that the same retail price prevails under both vertical integration and separation with Bertrand competition. It would be of interest to study how these findings are sensitive to modelling assumptions.

providers then they pay a wholesale access charge w. We assume that this charge is regulated, while the retail market is not[18].

The upstream firm undertakes infrastructure investment to upgrade the quality of the access network. We assume that this firm incurs a quadratic cost $C(x) = x^2/2$, where x is the level of quality investment, which is for every potential user. We also assume that the firm has a constant marginal (per-user) cost of providing the essential input, which, without loss of generality, we normalize to zero. Downstream firms benefit from an increase in consumers' wtp for the value-added services they are enabled to provide on the basis of network investment[19]. For simplicity, we normalize any downstream cost to zero.

We consider three alternative scenarios, where the upstream firm respectively is vertically integrated with downstream firm i, functionally separated, or structurally separated. In the following sections, first we analyze separately these scenarios, and then compare the results obtained to evaluate how the vertical industry structure affects incentives to invest in network quality and, more generally, social welfare. We relegate formal proofs to the Appendix.

We define a three-stage game of complete information. The timing is as follows: (i) the regulator sets the wholesale access charge w, (ii) the access owner (either vertically integrated or separated) sets the investment in network quality x, (iii) firm i (either vertically integrated or separated) and the rival firm e simultaneously choose retail prices p_i and p_e. As usual, we solve the game backwards.

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[18] The newly revised NRF prescribes that regulation focus on bottlenecks and retail remedies be withdrawn as far as possible. While wholesale broadband access is in the list of relevant markets, retail broadband access is not.

[19] We assume that there is no uncertainty about costs and returns on quality investment.

3.1 Vertical integration

The first scenario is one of vertical integration. We assume that retail services are vertically differentiated and consumers have a higher wtp for the incumbent's service, since the following conditions hold: i) vertical integration allows firm *i* to exploit better operational coordination between wholesale and retail activities than the rival firm; and ii) firm *i*'s retail subsidiary has a higher ability than the rival firm to benefit from quality investment[20].

Let $s+x$ be consumer *s*'s valuation of the incumbent's product, where s is the consumer's wtp for the basic service (that is, broadband internet access), which is uniformly distributed within the interval $[0,1]$, and x is the increase in wtp for the value-added services that firm *i* may offer on the basis of the quality-improving investment in the access network. Thus, consumers are heterogeneous in their valuation of the basic service, while they are homogeneous in their valuation of advanced services. On the other hand, consumer *s*'s valuation of the rival firm's product is $\gamma \cdot s + \delta \cdot x$, where $1-\gamma$ measures the loss of operational coordination due to the fact that firm *e* is not vertically integrated (alternatively, γ measures the perceived quality of firm *e*'s basic service), while δ measures the spillover effect, that is, firm *e*'s ability to transform one unit of quality investment into valuable services to end-users (alternatively, $1-\delta$ measures the reduction in the input quality provided to the rival firm). For simplicity, we assume that $\gamma \in (2/3,1)$ and $\delta \in (2/3,1)$.

We assume that consumers have unit demands. If $s + x - p_i > \gamma \cdot s + \delta \cdot x - p_e$ then consumer *s* decides to buy from the incumbent rather than the rival firm, because of a higher net utility (otherwise, consumer *s* buys from firm *e*). However, if net utilities are both

[20] The source of the latter competitive advantage can be twofold. On the one hand, firm *i* may have exclusive or privileged access to premium content compared with the rival firm with a smaller customer base. On the other hand, firm *i* may react to access regulation by using non-price discrimination, thus providing the downstream rival with a lower-quality input than her subsidiary (see e.g. Mandy and Sappington, 2007).

negative, then consumer s neither buys from the incumbent nor from the rival firm. Thus, we allow for partial market participation, where low-wtp consumers may not be active. Since the (perceived) quality of the incumbent's product is higher than the rival firm's product, then high-wtp consumers buy from firm i.

We derive the demand curves of the two firms by identifying the locations of two specific consumers. The first consumer, denoted as $\hat{s}$, is the one that is indifferent between buying from either of the two firms. It follows that $\hat{s} + x - p_i = \gamma \cdot \hat{s} + \delta \cdot x - p_e$ must hold (where net utilities are both positive). Hence, we have $\hat{s} = \frac{p_i - p_e - (1-\delta)x}{1-\gamma}$. The second consumer, denoted as $\bar{s}$, is the one that is indifferent between buying from firm e or not buying at all, namely, the marginal consumer. It follows that $\gamma \cdot \bar{s} + \delta \cdot x - p_e = 0$ must hold. Hence, we have $\bar{s} = \frac{p_e - \delta \cdot x}{\gamma}$. Since consumers have unit demands and are uniformly distributed within the interval $[0,1]$ then firms' demand curves are linear, and can be expressed respectively as $q_i = 1 - \hat{s}$ and $q_e = \hat{s} - \bar{s}$, where $1 \geq \hat{s} \geq \bar{s} \geq 0$ must hold for satisfying feasibility constraints on quantities (i.e. $q_i \geq 0$, $q_e \geq 0$ and $q_i + q_e \leq 1$). Inserting for $\hat{s}$ and $\bar{s}$, we obtain that:

$$q_i = 1 + \frac{1}{1-\gamma}((1-\delta)x - p_i + p_e); \quad q_e = \frac{1}{1-\gamma}\left(\frac{(1-\delta)}{\gamma}x + p_i - \frac{1}{\gamma}p_e\right).$$

Firms' profit functions can be written as:

$$\pi_i = p_i q_i + w q_e - \frac{x^2}{2}; \quad \pi_e = p_e q_e - w q_e.$$

Inserting for quantities, we have:

$$\pi_i = \left(1 + \frac{1}{1-\gamma}((1-\delta)x - p_i + p_e)\right)p_i + \frac{w}{1-\gamma}\left(\frac{(1-\delta)}{\gamma}x + p_i - \frac{1}{\gamma}p_e\right) - \frac{x^2}{2};$$

$$\pi_e = \frac{p_e - w}{1-\gamma}\left(\frac{(1-\delta)}{\gamma}x + p_i - \frac{1}{\gamma}p_e\right).$$

We define social welfare under vertical integration as $W = \pi_i + \pi_e + CS$, that is, the sum of firms' profits and consumer surplus $CS = \int_{\hat{s}}^{1}(s + x - p_i)ds + \int_{\bar{s}}^{\hat{s}}(\gamma \cdot s + \delta \cdot x - p_e)ds$.

Solving the game, we obtain the following results. For any given γ, we distinguish two cases. If firm *e*'s ability to exploit firm *i*'s investment is sufficiently high (that is, if $\delta \geq \delta^I(\gamma)$, where superscript *I* denotes the scenario of vertical integration), then we find a corner solution of downstream duopoly where each consumer purchases the service[21]. This occurs since the first-stage access charge that is obtained by solving the unconstrained welfare maximization problem affects the second-stage quality investment so as the feasibility constraint $\bar{s} \geq 0$ is binding. Hence, we find the optimal investment $\bar{x}(w)$ by solving the equation $\bar{s} = s(x,w) = 0$ with respect to *x*, and then we find the optimal access charge $\overline{w}^I$ by imposing the first-order condition on social welfare.

Alternatively, if the investment spillover is limited (that is, if $\delta < \delta^I(\gamma)$) then we find a corner solution of downstream monopoly where all consumers purchase the service from the incumbent. In such a case, both feasibility constraints $\hat{s} \geq \bar{s} \geq 0$ are binding. Hence, we find the optimal investment $\hat{x}(w)$ by solving $\hat{s}(x,w) = 0$ with respect to *x*, and the optimal access charge $\hat{w}^I$ by solving $\hat{s}(\hat{x}(w), w) = \bar{s}(\hat{x}(w), w) = 0$.

Proposition 1 below proves the results, while Table 1 summarizes the outcome of the game in terms of firms' market shares, quality investment, access charge, and social welfare.

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[21] Since we have assumed partial participation, then the marginal consumer's net utility is equal to zero even at the zero-location.

Proposition 1. Under vertical integration, for any given $\gamma \in (2/3,1)$ *there is a critical value of the spillover effect* $\delta^I(\gamma) = \frac{4+\gamma}{2} - \frac{\sqrt{3(4-\gamma^2)}}{2} \in (2/3,1)$ *such that at the equilibrium of the game we have what follows:*

(a) If $\delta^I(\gamma) \le \delta < 1$ *then the optimal access charge is* $\overline{w}^I$*, the optimal quality investment is* $\overline{x}^I$*, and there is a corner solution of a downstream duopoly where all consumers purchase the service.*

(b) If $\frac{2}{3} < \delta < \delta^I(\gamma)$ *then the optimal access charge is* $\hat{w}^I$*, the optimal quality investment is* $\hat{x}^I$*, and there is a corner solution of a downstream monopoly where all consumers purchase the service from the vertically integrated firm.*

Proof. See Appendix.

Let us now analyze how the basic model parameters (γ, that is firm *e*'s level of operational coordination, and δ, that is the demand-side spillover from investment to firm *e*) affect the players' strategic choices under vertical integration.

First, we consider the case when vertical integration is compatible with a downstream duopoly (where all consumers are active). A higher firm *e*'s operational coordination reduces quality differentiation between services and enforces retail competition (since we have $\partial(p_i - w)/\partial\gamma \le 0$, $\partial(p_e - w)/\partial\gamma \le 0$ and $\partial(p_i - p_e)/\partial\gamma \le 0$)[22], thus having a positive impact on consumer surplus ($\partial CS/\partial\gamma \ge 0$). While the OLO is able to get higher profit ($\partial\pi_e/\partial\gamma \ge 0$), the retail portion of the integrated firm's profit decreases ($\partial((p_i - w)q_i)/\partial\gamma \le 0$). To avoid

[22] We rewrite the integrated firm's profit so as to highlight the role of the transfer charge *w*. This allows us to decompose the firm's profit in two portions respectively related to the retail and wholesale segments.

that the incumbent reduces investment because of the loss in the retail segment, the regulator raises the access charge ($\partial w/\partial \gamma \geq 0$) so as wholesale revenues rise ($\partial((q_i + q_e)w)/\partial \gamma \geq 0$). This induces the incumbent to invest more ($\partial x/\partial \gamma \geq 0$). Nonetheless, the net effect on the integrated firm's profit is so much negative that social welfare reduces ($\partial W/\partial \gamma \leq 0$).

On the other hand, a higher investment spillover to firm *e* reduces quality differentiation between services ($\partial(p_i - p_e)/\partial \delta \leq 0$). While the incumbent's mark-up and profit in the retail market are consequently reduced ($\partial(p_i - w)/\partial \delta \leq 0$ and $\partial((p_i - w)q_i)/\partial \delta \leq 0$), the OLO achieves a higher retail margin and profit ($\partial(p_e - w)/\partial \delta \geq 0$ and $\partial \pi_e/\partial \delta \geq 0$)[23]. The net effect of these changes on consumer surplus is negative ($\partial CS/\partial \delta \leq 0$). The incumbent's retail profit loss is offset by the gain in wholesale profit ($\partial((q_i + q_e)w - x^2/2)/\partial \delta \geq 0$ and $\partial \pi_i/\partial \delta \geq 0$). We have to distinguish two alternative cases. When the investment spillover is high enough, to exploit the OLO's higher ability to use investment the regulator raises the access charge ($\partial w/\partial \delta \geq 0$) so as wholesale revenues rise ($\partial((q_i + q_e)w)/\partial \delta \geq 0$). This induces higher investment and welfare ($\partial x/\partial \delta \geq 0$ and $\partial W/\partial \delta \geq 0$), despite the incumbent raises the retail price (less than the OLO). In the case when the spillover is low, the regulator fosters competition by reducing the access charge as the spillover rises ($\partial w/\partial \delta \leq 0$), even if this dilutes investment ($\partial x/\partial \delta \leq 0$). In such a case, the incumbent reduces the retail price. However, the overall impact on social welfare is negative ($\partial W/\partial \delta \leq 0$).

[23] Both a higher operational coordination and a higher investment spillover make the OLO's service more similar to the incumbent's one. However, a higher spillover reduces the heterogeneity of consumers served by the OLO (since their wtp rises by the same amount), while a higher operational coordination amplifies their heterogeneity. In other words, a higher spillover means richer and less heterogeneous consumers to the OLO, while a higher operational coordination means richer and more heterogeneous consumers to the OLO.

Let us now consider the case when vertical integration leads to a downstream monopoly (where all consumers are active). A higher firm *e*'s operational coordination makes the potential entrant more competitive and reduces the incumbent's retail mark-up (in addition, the regulator reduces the access charge that should be paid by an entrant). Therefore, consumer surplus benefits from stronger potential competition. The retail profit loss induces the incumbent to reduce quality investment. The overall impact on the incumbent's profit and on social welfare is negative when the investment spillover is sufficiently low, and positive when it is high enough.

On the other hand, a higher investment spillover reduces the incumbent's mark-up. In order to exploit the OLO's higher ability to use quality investment, the regulator raises the access charge. This in turn leads the incumbent to raise investment, but also the retail price (so that the gain in wholesale revenues exceeds the retail profit loss). The overall impact on consumer surplus is negative, while the incumbent's profit and social welfare are higher when the spillover is low enough, but lower when it is sufficiently high (indeed, they strongly depend on the level of quality investment).

3.2 Functional separation

In the second scenario, we assume that the upstream entity that manages the local network, denoted as firm *a*, is functionally separated from downstream firm *i*. Different from vertical integration, functional separation does not allow the upstream firm to influence the pricing strategy of the affiliated downstream firm. Therefore, firm *i* maximizes own (downstream) profit without taking into account firm *a*'s profit. However, as with vertical integration, the upstream unit decides the level of investment in network quality by considering the integrated profit (i.e. including firm *i*'s profit), subject to the obligation to recover the investment cost exclusively through upstream revenues (so as to avoid unfair cross-subsidies between upstream and downstream markets).

Under functional separation, both downstream firms *i* and *e* are provided with the same input quality at the same access charge. Thus, we assume that downstream firms have the same ability to transform input into output, that is, they equally benefit from quality investment. Functional separation does not prevent affiliated downstream and upstream units from achieving an effective operational coordination. For simplicity, we assume that operational coordination for the functionally separated downstream unit is the same as the integrated firm's retail subsidiary[24]. Hence, under functional separation high-wtp consumers still purchase from firm *i*.

Let $\beta \cdot x$ be the increase in consumers' wtp for the value-added services provided by any downstream firm on the basis of network investment, where $1 > \beta \geq \delta$[25]. Consumer s purchases firm *i*'s product if $s + \beta \cdot x - p_i > \gamma \cdot s + \beta \cdot x - p_e$, unless both net utilities are negative, in which case consumer s does not buy at all. Given the assumptions of unit demand and uniform distribution of consumers within the interval $[0,1]$, firms' demand curves are linear and can be written as:

$$q_i = 1 - \hat{s} = 1 - \frac{p_i - p_e}{1-\gamma}; \quad q_e = \hat{s} - \bar{s} = \frac{p_i - p_e}{1-\gamma} - \frac{p_e - \beta \cdot x}{\gamma},$$

provided that the feasibility constraints $1 \geq \hat{s} \geq \bar{s} \geq 0$ hold.

Profit functions respectively of firms *a*, *i* and *e* are the following:

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[24] Operational coordination under functional separation should be slightly lower than the one under vertical integration. However, since operational coordination under both scenarios is much larger than under structural separation, we can reasonably simplify the analysis by assuming that it is the same under both scenarios.

[25] Thus, under vertical separation, both downstream firms' abilities to use network investment are not lower than the rival firm under vertical integration, but are lower than the integrated firm's retail subsidiary.

$$\pi_a = w(q_i + q_e) - \frac{x^2}{2}; \quad \pi_i = p_i q_i - w q_i; \quad \pi_e = p_e q_e - w q_e.$$

However, firm *a* sets the investment level *x* by maximizing profit $\pi_a + \pi_i$ (subject to $\pi_a \geq 0$). Inserting for quantities, we obtain:

$$\pi_a + \pi_i = \left(1 - \frac{p_i - p_e}{1-\gamma}\right)p_i + \left(\frac{p_i - p_e}{1-\gamma} - \frac{p_e - \beta \cdot x}{\gamma}\right)w - \frac{x^2}{2};$$

$$\pi_i = \left(1 - \frac{p_i - p_e}{1-\gamma}\right)(p_i - w);$$

$$\pi_e = \left(\frac{p_i - p_e}{1-\gamma} - \frac{p_e - \beta \cdot x}{\gamma}\right)(p_e - w).$$

We define social welfare under functional separation as $W = (\pi_a + \pi_i) + \pi_e + CS$, that is, the sum of firms' profits and consumer surplus $CS = \int_{\hat{s}}^{1} (s + \beta \cdot x - p_i)ds + \int_{\bar{s}}^{\hat{s}} (\gamma \cdot s + \beta \cdot x - p_e)ds$.

Solving the game, we obtain the following results. For any given γ, we distinguish two cases. If downstream firms' ability to exploit network investment is sufficiently high (that is, if $\beta > \beta^f(\gamma)$, where superscript *f* denotes the scenario of functional separation), then we find a corner solution of downstream duopoly where each consumer purchases the service. Indeed, the first-stage access charge that is obtained by solving the unconstrained welfare maximization problem induces firm *a* to raise the second-stage quality investment so that the marginal consumer is located at zero (since the feasibility constraint $\bar{s} \geq 0$ is binding), and purchases from firm *e*. Hence, we find the optimal investment $\bar{x}(w)$ by solving the equation $\bar{s} = s(x, w) = 0$ with respect to *x*, and then we find the optimal access charge $\overline{w}^f$ by imposing the first-order condition on social welfare.

Alternatively, if the investment spillover is limited (that is, if $\beta \leq \beta^f(\gamma)$) then we have a downstream duopoly where low-wtp consumers do not buy at all. In such a case, the feasibility constraints on the marginal and on the indifferent consumer are not binding.

Proposition 2 proves the above discussed results, while Table 2 reports the outcome of the game in terms of firms' market shares, quality investment, access charge, and social welfare.

Proposition 2. Under functional separation, for any given $\gamma \in (2/3,1)$ *there is a critical value of the spillover effect* $\beta^f(\gamma) \in (2/3,1)$ *such that at the equilibrium of the game we have that:*

(a) If $\beta^f(\gamma) < \beta < 1$ *then the optimal access charge is* $\overline{w}^f$*, the optimal quality investment is* $\overline{x}^f$*, and there is a corner solution of downstream duopoly where all consumers purchase the service.*

(b) If $2/3 < \beta \leq \beta^f(\gamma)$ *then the optimal access charge is* $\widehat{w}^f$*, the optimal quality investment is* $\widehat{x}^f$*, and there is a downstream duopoly where low-wtp consumers do not buy at all.*

Proof. See Appendix, where we also relegate the expression of $\beta^f(\gamma)$.

Let us now analyze how the basic model parameters (γ, that is firm *e*'s level of operational coordination, and β, that is the demand-side spillover from investment to both downstream firms) affect the players' strategic choices under functional separation.

We first consider the case when all consumers purchase the service. A higher firm *e*'s operational coordination reinforces retail competition by reducing quality differentiation between services. This in turn positively affects consumer surplus, and negatively affects downstream firms' profits. The regulator raises the access charge, and thus wholesale revenues ($\partial \pi_a / \partial \gamma \geq 0$), so as to induce firm *a* to guarantee the same investment level despite firm i's profit loss ($\partial x/\partial\gamma = 0$)[26]. However, the functionally separated incumbent loses profit ($\partial(\pi_a + \pi_i)/\partial\gamma \leq 0$). The overall impact on social welfare is positive.

Similarly, a higher spillover to downstream firms reduces quality differentiation between services ($\partial(p_i - p_e)/\partial\beta \leq 0$), so as retail competition reduces firms' mark-ups and profits ($\partial(p_i - w)/\partial\beta \leq 0$, $\partial(p_e - w)/\partial\beta \leq 0$, $\partial\pi_i/\partial\beta \leq 0$ and $\partial\pi_e/\partial\beta \leq 0$), while it raises consumer surplus ($\partial CS/\partial\beta \geq 0$). The regulator raises the access charge ($\partial w/\partial\beta \geq 0$) so as to exploit downstream firms' higher abilities of using quality investment, thus inducing higher wholesale revenues $\partial((q_i + q_e)w)/\partial\beta \geq 0$. This induces quality investment to rise ($\partial x/\partial\beta \geq 0$). On the whole, the functionally separated incumbent's profit also rises ($\partial(\pi_a + \pi_i)/\partial\beta \geq 0$). The overall impact on welfare is positive ($\partial W/\partial\beta \geq 0$).

Let us now consider the case when some consumers stay out of the market. A higher firm e's operational coordination reduces quality differentiation as well as downstream firms' markups and profits. The overall quantity sold also reduces due to lower quality differentiation. When the spillover is sufficiently low, the regulator raises the access charge and thus wholesale revenues ($\partial((q_i + q_e)w)/\partial\gamma \geq 0$) to contain the negative impact of the demand contraction on firm a's investment ($\partial x/\partial\gamma \leq 0$). However, the wholesale profit gain partially balances the retail profit loss ($\partial(\pi_a + \pi_i)/\partial\gamma \leq 0$). The overall impact on consumer surplus and social welfare is positive. Things are different when the spillover is sufficiently high. In such a case, lower quality differentiation moderately affects firm a's investment. Therefore, the regulator contrasts the demand contraction by reducing the access charge ($\partial w/\partial\gamma \leq 0$), and consequently inducing lower retail prices. However, this causes a loss of

[26] Thus, quality investment becomes independent of operational coordination.

quality investment. The overall impact on the functionally separated firm's profit, consumer surplus and social welfare is negative.

Finally, a higher spillover to downstream firms increases all consumers' wtp. The regulator exploits downstream firms' higher abilities to use quality investment by raising the access charge which, in turn, induces higher investment (but also higher retail prices). Both firm *a*'s and the whole functionally separated firm's profits rise, and so does welfare. When the spillover is sufficiently low, but the OLO's operational coordination is sufficiently high (i.e. consumers of both downstream firms are sufficiently heterogeneous), retail competition reduces demand and consumer surplus, as well as downstream firms' mark-ups and profits. In the case when the spillover is sufficiently high, but the OLO's operational coordination is sufficiently low (i.e. consumers of both downstream firms are sufficiently homogeneous), demand and consumer surplus rise, and so do downstream firms' mark-ups and profits.

3.3 Structural separation

In the third scenario, we assume that upstream firm *a* is structurally separated from downstream firm *i*. Since firm *a* does not have any affiliated entity in the retail market, then firm *a*'s profit entirely derives from selling wholesale access to downstream firms (at a regulated charge). Thus, firm *a* sets the investment level *x* on the sole basis of that profit.

As with functional separation, under structural separation firm *a* provides both downstream firms with the same input quality at the same access charge. On the other hand, structural separation reduces operational coordination. We assume that downstream firms have a lower operational coordination with upstream activities than the integrated firm's retail subsidiary (or firm *a*'s affiliated retail entity under functional separation). We also assume that downstream firms have the same operational coordination. Hence, downstream firms are now identical to consumers since they compete with a homogeneous product.

Let $\beta \cdot x$ be the increase in consumers' wtp for the value-added services provided by any downstream firm on the basis of quality investment, where $1 > \beta \geq \delta$. Consumer s's net utility respectively is $\gamma \cdot s + \beta \cdot x - p_i$ or $\gamma \cdot s + \beta \cdot x - p_e$, depending on the firm the consumer purchases from. Since retail services are homogeneous, then symmetrical downstream firms competing *à la* Bertrand set the retail price at the production cost, that is, the wholesale access charge. It follows that the marginal consumer is located at $\bar{s} = \frac{w - \beta \cdot x}{\gamma}$, and the overall demand is equal to $q_i + q_e = 1 - \bar{s}$ (given the assumptions of unit demand and uniform distribution of consumers within $[0,1]$), provided that the feasibility constraints $1 \geq \bar{s} \geq 0$ hold.

Profit functions respectively of firms *a*, *i* and *e* are the following:

$$\pi_a = w(q_i + q_e) - \frac{x^2}{2}; \quad \pi_i = p_i q_i - w q_i; \quad \pi_e = p_e q_e - w q_e.$$

Inserting for quantities and $p_i = p_e = w$, we obtain:

$$\pi_a = w\left(1 - \frac{w - \beta \cdot x}{\gamma}\right) - \frac{x^2}{2}; \quad \pi_i = 0; \quad \pi_e = 0.$$

We define social welfare under structural separation as $W = \pi_a + \pi_i + \pi_e + CS$, where $CS = \int_{\hat{s}}^{1} (\gamma \cdot s + \beta \cdot x - p_i) ds + \int_{\bar{s}}^{\hat{s}} (\gamma \cdot s + \beta \cdot x - p_e) ds = \int_{\bar{s}}^{1} (\gamma \cdot s + \beta \cdot x - w) ds$ is consumer surplus.

Following exactly the same reasoning as under functional separation, we obtain the results that are summarized in Proposition 3, while Table 3 reports the outcome of the game in terms of firms' market shares, quality investment, access charge, and social welfare (superscript *s* denotes the scenario of structural separation).

Proposition 3. Under structural separation, for any given $\gamma \in (2/3,1)$ there is a critical value of the spillover effect $\beta^s(\gamma) = \sqrt{\gamma} \in (2/3,1)$ such that at the equilibrium of the game we have that:

(a) If $\beta^s(\gamma) < \beta < 1$ *then the optimal access charge is* $\overline{w}^s$*, the optimal quality investment is* $\overline{x}^s$*, and there is a corner solution of downstream duopoly where all consumers purchase the service.*

(a) If $\frac{2}{3} < \beta \leq \beta^s(\gamma)$ *then the optimal access charge is* $\widehat{w}^s$*, the optimal quality investment is* $\widehat{x}^s$*, and there is a downstream duopoly where low-wtp consumers do not buy at all.*

Proof. See Appendix.

Let us now analyze how the basic model parameters (γ, that is both downstream firms' level of operational coordination, and β, that is the demand-side spillover from investment to both downstream firms) affect the players' strategic choices under structural separation. Since downstream firms are perfectly symmetric, retail price competition extracts any extra profit and there is a unique retail price that is equal to the (regulated) access charge.

When all consumers purchase the service, a higher operational coordination does not have an impact on either the access charge or the investment level. In fact, a higher coordination does not affect the lowest-wtp consumer's wtp, and thus the price this consumer pays, which is exactly the access charge. As a consequence, wholesale revenues do not change, and so does investment. However, both consumer surplus and social welfare increase.

On the other hand, a higher spillover to downstream firms induces the regulator to raise the access charge so that wholesale revenues and profits also rise. Thus, we have a higher investment. While there is no impact on consumer surplus, welfare is positively affected.

When some consumers are not active, a higher operational coordination raise the overall quantity sold when the operational coordination is sufficiently high, but the spillover is low (i.e. consumers of both downstream firms are sufficiently heterogeneous). In such a case, the regulator induces higher wholesale revenues by raising the access charge, in order to contain the reduction of firm *a*'s investment. In fact, new active consumers are a source of revenue that allows firm *a* to invest less (in other words, there is a sort of substitution effect between higher operational coordination and lower quality investment in terms of consumers' wtp). The overall impact on wholesale profits, consumer surplus, and social welfare is positive. In the case when the operational coordination is low, but the spillover is sufficiently high (i.e. consumers of both downstream firms are sufficiently homogeneous), the overall demand does shrink. The regulator contrasts the demand loss by reducing the access charge and consequently inducing lower retail prices (but also lower investment). The overall impact is positive on firm *a*' profit, but negative on consumer surplus and social welfare.

On the other hand, a higher spillover to downstream firms increases all consumers' wtp. In order to exploit downstream firms' higher ability to use quality investment, the regulator raises the access charge which, in turn, induces higher investment and higher retail prices. Firm *a*'s profit rises, and so does social welfare. When the spillover is low, but the operational coordination is sufficiently high, retail competition reduces demand and thus consumer surplus, while we have the opposite effect when the spillover is sufficiently high, but the operational coordination is low.

3.4 Comparison of results under different vertical industry structures

Let us now compare the outcome of the game in the three alternative scenarios, particularly in terms of quality investment and social welfare. For both clarity and conciseness, in what follows we analyze and discuss the main results by means of two-dimensional $\gamma\beta$ (i.e. 'operational coordination' vs. 'spillover from investment') diagrams[27]. In detail, we set the investment spillover to the rival firm under vertical integration to three different values,

[27] However, all formal proofs are available from the authors on request.

namely, (a) exactly equal to the investment spillover under vertical separation; (b) close to the lowest feasible value (i.e. 2/3); and (c) at an intermediate value between cases (a) and (b). Thus, given $k \in (0,100]$, we set $\delta(k) = (1 - k/100) \cdot 2/3 + (k/100) \cdot \beta$ and we consider the cases of $\delta_{100} = \delta(100)$, $\delta_{50} = \delta(50)$ and $\delta_1 = \delta(1)$. It follows that we reduce the parameter space to three $\gamma\beta$ diagrams relative to the δ_{100}, δ_{50} and δ_1 cases. In each diagram, white, light gray and dark gray areas respectively indicate that the relevant variable takes the highest value under vertical integration, functional separation and structural separation. Given a $\gamma\beta$ diagram related to δ_k, the area below the curve denoted as $\mu_k(\gamma)$ is characterized by monopoly under vertical integration, while in the area above $\mu_k(\gamma)$ vertical integration allows duopoly at the equilibrium (if curve $\mu_k(\gamma)$ is not reported at all, then there is a monopoly under vertical integration for any γ and β).

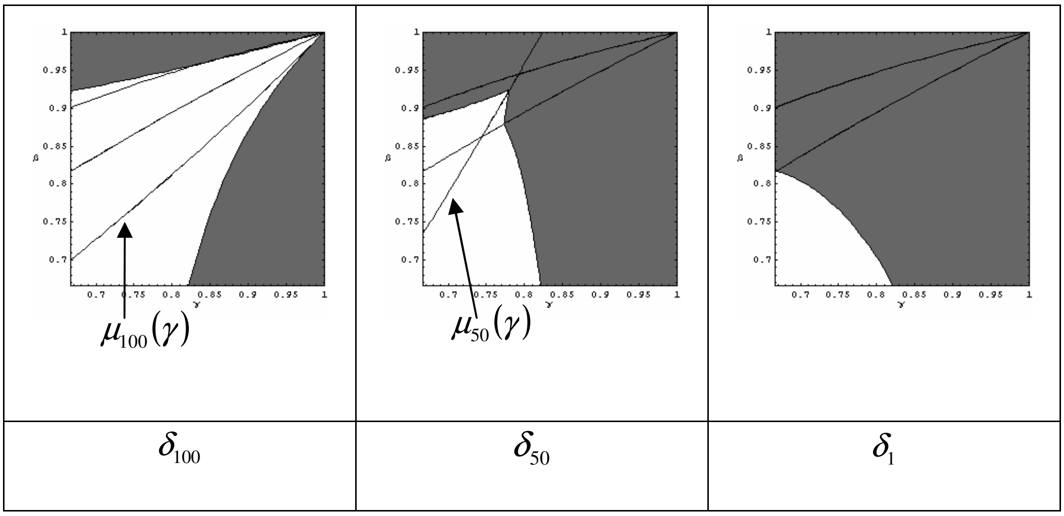

Figure 1. Separation vs. integration: a comparison of the access charge.

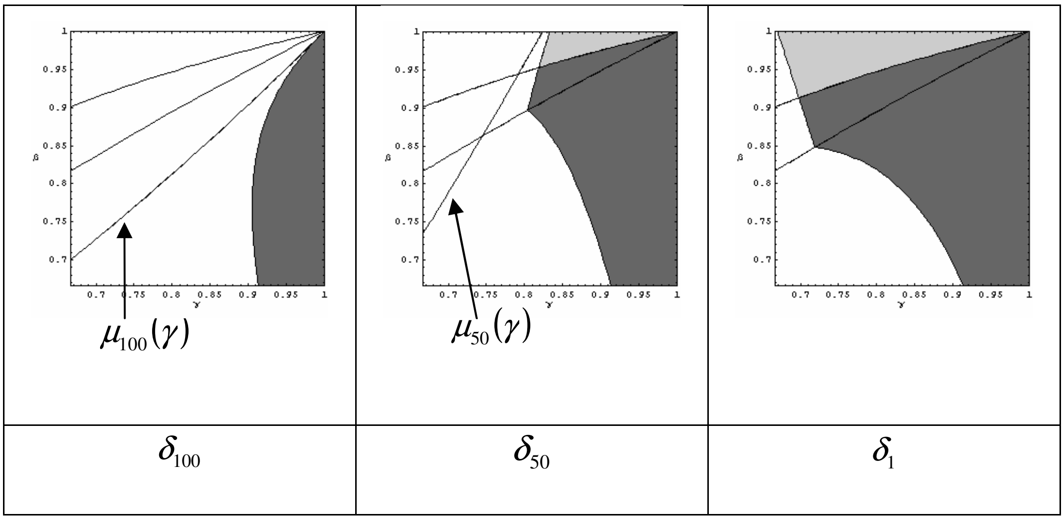

Figure 2. Separation vs. integration: a comparison of quality investment.

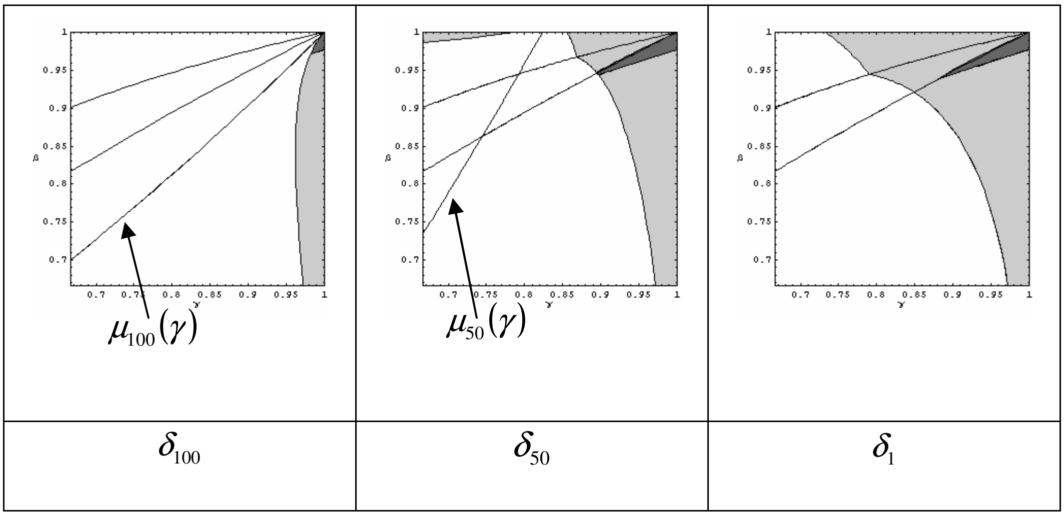

Figure 3. Separation vs. integration: a comparison of social welfare.

First, we find the expected result that vertical separation induces higher downstream competition than integration. In particular, while under vertical separation the downstream market is always a duopoly, in some circumstances the vertically integrated firm invests so much as to achieve a downstream monopoly (even though the access charge is regulated).

A less intuitive result is that vertical separation is not always associated with a higher (regulated) access charge (see Figure 1)[28]. In addition, we find out that a higher (regulated) access charge does not always imply higher investment (see figures 1 and 2).

More interestingly, we find that generally vertical separation does not face the trade-off between promoting competition and ensuring investment. Indeed, our results show that vertical separation more effectively induces higher quality investment exactly when it also effectively induces downstream competition, because the integrated firm can severely discriminate the downstream rival (see Figure 2[29]). Under the same circumstances, when the access owner's investment is higher under vertical separation than integration, this is also welfare-improving[30]. Figure 3 shows that this occurs particularly under functional separation.

The results obtained show that, in the case whereby vertical integration induces a downstream monopoly, there are many circumstances where both quality investment and social welfare benefit from either functional or structural separation, namely, when there is a small loss of operational coordination, or the investment spillover is high. On the other hand, when there is a duopoly under integration, a necessary condition for separation to raise investment is that separation does not reduce market participation. This condition is also sufficient when the investment spillover is high enough. We remark that when the operational coordination is sufficiently high, so as it dominates the spillover effect (i.e. when γ is high and $\beta < \gamma$), welfare maximization implies a loss in quality investment, since investment is always higher under structural separation, but functional separation generally raises welfare.

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[28] However, the access charge is always higher under structural separation than under functional separation.

[29] We remark that in the same areas where structural separation induces higher investment, functional separation dominates integration. Moreover, in the area where functional separation induces higher investment, functional and structural separation indeed induce the same level of investment.

[30] Welfare results are gross of the one-off cost of divestment of the integrated firm.

On the whole, the results obtained point out a unique trend that relates both quality investment and welfare to the spillover effect. In fact, the larger the difference between the spillover effect under separation and integration, the wider the area where both investment and welfare are higher under separation than integration. This means that separation is particularly effective when the vertically integrated firm is able to significantly reduce the input quality to the rival firm. In such cases, ensuring 'equivalence of inputs' to downstream competitors through vertical separation also produces higher investment in the quality of the access network.

4 Concluding remarks

Mandatory vertical separation of the dominant firm in fixed telecommunications can be both an effective and proportionate regulatory remedy to prevent price and, above all, non-price discrimination of downstream rivals, particularly in those countries where (i) the local access network is an enduring economic bottleneck, so that both within-platform and between-platform end-to-end competition is not sustainable in the mass market, and (ii) the vertically integrated firm has repeatedly breached either the regulatory contract or antitrust laws.

One of the most critical issues is the common presumption that vertical separation of the bottleneck owner (either of the functional or the structural type) would cause a decline in investment in network quality or size. This presumption has been supported by some literature findings that are relevant to specific network industries (such as energy and railways).

In this paper, we have assessed whether or not this presumption does hold for fixed telecommunications, given that several incumbents worldwide have recently announced or undertaken massive investment in deploying new access networks, the so-called NGAs. We have shown that quality-enhancing network investment may be higher under each type of vertical separation than integration, particularly if the integrated firm is far from ensuring equivalent access to the bottleneck input to downstream competitors. Consequently, vertical separation more effectively improves quality investment exactly when it is also an effective remedy to foster competition. We have also shown that, due to the investment cost, it is mostly functional (rather than structural) separation that may improve social welfare compared with an integrated structure. When the integrated firm forecloses the downstream rival, a necessary condition for separation to raise welfare is that it raises investment.

We have a higher access charge and higher investment under structural rather than functional separation. However, there are no clear-cut results when vertical separation is compared with integration. In fact, separation does not always imply a higher access charge, and a higher charge in turn does not always imply higher investment.

These results follow from having explicitly recognized that the optimal (regulated) access charge in view of quality investment depends on the different retail competitive conditions associated with the different vertical industry structures, and from having considered two basic features of the retail broadband access market, namely, imperfect price competition with differentiated products and partial participation.

We have obtained these results albeit our model takes account of efficiency losses induced by vertical separation, due to arising coordination problems between upstream and downstream operational and investment activities. Admittedly, vertical separation is socially beneficial when it generates a small loss of operational coordination and/or the spillover from quality investment is sufficiently high.

The results obtained depend in part on model formulation, and thus on the specific assumptions on demand and cost functions, as well as the nature of downstream competition. Nonetheless, the qualitative result that vertical separation may raise both quality investment and welfare is not diluted in some alternative model specifications.

Indeed, vertical separation creates a level playing field for downstream competition. As a consequence, we have removed the assumption that the incumbent has a higher ability to use network investment in order to provide advanced services, which does hold under vertical integration. We have thus stressed that under vertical separation the incumbent can no longer enforce input quality discrimination. However, we have ruled out the cases where service providers have a different ability to use quality investment in order to provide advanced services[31], or where an open access regime to the essential input fosters retail product innovation so much as to offset potential hold-up problems induced by vertical separation. It follows that we may have underestimated the positive impact of vertical separation on investment, and possibly on welfare.

An alternative model formulation would be one of horizontal product differentiation *à la* Hotelling in the retail broadband access market. A basic assumption of the Hotelling model is full market participation, which means that all consumers are always served. Since vertical separation often reduces the retail quantity sold in our vertical differentiation model with partial participation, then it is plausible that the positive effect of separation on investment and welfare would be preserved, and possibly toughened with horizontal differentiation.

Finally, there are several dimensions along which our research can be extended in future work. First, there is the risk that vertical separation reduces incentives for new entrants to invest in competitive infrastructures. This tendency may be strengthened by the costs and technical architectures of NGAs. It would thus be of interest to assess the impact of structural changes in the industry on the prevailing regulatory model in Europe, which is based on the paradigm of the ladder of investment (ERG, 2006)[32].

[31] Matteucci and Reverberi (2005a) consider this possibility in a model of international trade, when comparing welfare effects of different exhaustion regimes of intellectual property rights.

[32] According to this paradigm, service-based and facility-based competition are complement and not substitute entry modes. Thus, developing an alternative network is not so much a question of time *per se* as is related to building a customer base that increases reputation and brand loyalty to the OLO, and reduces the (unit) cost and the risk of network investment. See Avenali et al. (2009) for a formal analysis of the ladder model.

Second, there is the risk that the deployment of NGAs amplifies the digital divide between the most and the least developed areas of the country. This poses the question whether or not broadband access should be part of universal service obligations[33], and whether and how public intervention may bridge the broadband gap. It would thus be appropriate to study the feasibility of a model of differentiated wholesale regulation on a geographic basis, and to analyze the impact of the vertical industry structure on universal service cost and funding.

Appendix

Proof of Proposition 1. We solve the game backwards. First we find the third-stage optimal retail prices by the first-order condition on firms' profits (given that the second-order condition is always fulfilled):

$$\hat{p}_i = \frac{3w + 2(1-\gamma) + (2-\gamma-\delta)x}{4-\gamma}; \quad \hat{p}_e = \frac{(2+\gamma)w - \gamma(x-1+\gamma) + \delta(2-\gamma)x}{4-\gamma}.$$

At the second stage, firm i maximizes her profit with respect to quality investment. By the first-order condition on firm i's profit we find the optimal investment $\hat{x}(w) = \frac{(1-\gamma)((4-w)\gamma^2 - 4\gamma(2-\delta) + 8\delta w)}{\gamma(-7\gamma^2 + \gamma^3 + 4\gamma(4+\delta) - 2(4+(4-\delta)\delta))}$. Note that $\hat{x}(w)$ is a feasible solution if and only if firm i's profit function is concave and $1 \geq \hat{s}(\hat{x}(w), w) \geq \bar{s}(\hat{x}(w), w) \geq 0$. Computation yields that all these conditions hold when both $\gamma \leq \delta \leq \frac{1}{2}(3\gamma - \gamma^2)$ and $w' \leq w \leq w''$ hold, where $w' = \frac{\gamma((-3+\gamma)\gamma^2 - 2(\delta-2)\delta)}{2\gamma^3 - 4\delta^2(7+\delta) + \gamma(4+6\delta)}$ and $w'' = \frac{\gamma((-3+\gamma)(\gamma-2)\gamma + 4(\gamma-2)\delta + 2\delta^2)}{-4\gamma^2 + \gamma^3 + 2\delta(\delta-2) + \gamma(2+3\delta)}$.

[33] Matteucci and Reverberi (2005b) analyze this problem in a different context, that is, they assess welfare effects of public service obligations in pharmaceuticals.

In the remaining cases, either $\bar{s}(\hat{x}(w),w)\geq 0$ or $\hat{s}(\hat{x}(w),w)\geq 0$ does not hold. First, let $\bar{s}(\hat{x}(w),w)<0$ but $\hat{s}(\hat{x}(w),w)\geq 0$. In such a case, we find the optimal investment by solving the equation $\bar{s}(x,w)=0$, and obtain $\bar{x}(w)=\dfrac{\gamma-\gamma^2+w(2+\gamma)^2}{\gamma+2\delta}$. It is easy to verify that $\hat{s}(\bar{x}(w),w)\geq 0$ if and only if $w\leq\dfrac{(1-\gamma)\delta}{1-\delta}$. If $w>\dfrac{(1-\gamma)\delta}{1-\delta}$, then we have that $\hat{s}(\bar{x}(w),w)<0$. In such a case, we find the optimal investment by solving the equation $\hat{s}(x,w)=0$, and obtain $\hat{x}(w)=\dfrac{(1-\gamma)(2+w-\gamma)}{2-\gamma-\delta}$.

At the first stage, the regulator maximizes welfare with respect to the access charge. Assume that both $\gamma\leq\delta\leq\frac{1}{2}\left(3\gamma-\gamma^2\right)$ and $w'\leq w\leq w''$ hold, so that the second-stage optimal investment is $\hat{x}(w)$. Since the welfare function is concave in *w* then the regulator chooses the optimal access charge by the first-order condition $\dfrac{\partial W(\hat{x}(w),w)}{\partial w}=0$, and thus finds $\hat{w}$ (for brevity, we omit the expression of $\hat{w}$). However, computation yields that $\hat{w}$ is such that $w'\leq\hat{w}\leq w''$ cannot hold, so that the feasibility constraints $1\geq\hat{s}(\hat{x},\hat{w})\geq\bar{s}(\hat{x},\hat{w})\geq 0$ cannot be fulfilled. In such a case, the consumer at $s=0$ buys from firm *e* and the optimal investment level is $\bar{x}(w)$ if and only if $w\leq\dfrac{(1-\gamma)\delta}{1-\delta}$. Inserting for $\bar{x}(w)$ and solving for $\dfrac{\partial W(\bar{x}(w),w)}{\partial w}=0$, we find the access charge $\bar{w}^I=\dfrac{(\gamma-1)\left(\gamma(1+\gamma)^2-(-3+\gamma)\delta+(1+2\gamma)\delta^2\right)}{-1+3\gamma^2+\gamma^3+2\gamma(-1+\delta)^2+3(-2+\delta)\delta}$. With some algebra, we obtain that $\bar{w}\leq\dfrac{(1-\gamma)\delta}{1-\delta}$ holds if $\dfrac{4+\gamma}{2}-\dfrac{\sqrt{3(4-\gamma^2)}}{2}=\delta^I(\gamma)\leq\delta<1$.

In the case when $\dfrac{2}{3}<\delta<\delta^I(\gamma)$, we have that $\hat{s}(\bar{x}(\bar{w}),\bar{w})<0$. Hence, the consumer at $s=0$ buys from firm *i* and the optimal investment is $\hat{x}(w)$. Since $\hat{s}(\hat{x}(w),w)=0$, then the condition $\hat{s}(\hat{x}(w),w) \geq \bar{s}(\hat{x}(w),w) \geq 0$ is binding. It follows that the optimal access charge $\hat{w}^I$ is obtained by solving the equation $\hat{s}(\hat{x}(w),w) = \bar{s}(\hat{x}(w),w)$.■

Proof of Proposition 2. Let solve the game backwards. Given that the second-order condition is always fulfilled, we find the third-stage optimal retail prices by the first-order condition on firms' profits:

$$\widehat{p}_i(x,w) = \frac{-3w + (2+\beta \cdot x)(\gamma - 1)}{\gamma - 4}; \quad \widehat{p}_e(x,w) = \frac{-w(2+\gamma) + (\gamma-1)(2\beta \cdot x + \gamma)}{\gamma - 4}.$$

Inserting for $\widehat{p}_i(x,w)$ and $\widehat{p}_e(x,w)$, the feasibility constraints $1 \geq \hat{s}(x,w) \geq \bar{s}(x,w) \geq 0$ are satisfied in the following cases: (a) when $0 \leq w \leq \gamma/2$ and $0 \leq x \leq \frac{2w + \gamma + \gamma \cdot w - \gamma^2}{\beta(\gamma+2)}$, (b) when $w > \gamma/2$ and $\frac{2w - \gamma}{2\beta} \leq x \leq \frac{2w + \gamma + \gamma \cdot w - \gamma^2}{\beta(\gamma+2)}$. In the remaining cases, either $\bar{s}(x,w) \geq 0$ or $\hat{s}(x,w) \geq \bar{s}(x,w)$ does not hold ($\bar{s}(x,w) < 0$ when $x > \frac{2w + \gamma + \gamma \cdot w - \gamma^2}{\beta(\gamma+2)}$); $\hat{s}(x,w) < \bar{s}(x,w)$ when $w > \gamma/2$ and $0 \leq x < \frac{2w-\gamma}{2\beta}$).

At the second stage, firm *a* maximizes the joint profit (upstream-downstream) $\pi_a(x,w) + \pi_i(x,w)$ with respect to quality investment. The joint profit function is strictly concave in *x*. Hence, by the first-order condition on firm *a*'s profit we find the optimal investment $\widehat{x}(w) = \frac{\beta\left(8w + 4\gamma + \gamma^2(w-4)\right)}{\gamma\left((\gamma-4)^2 + 2\beta^2(\gamma-1)\right)}$. Since the welfare function $W(\widehat{x}(w),w)$ is strictly concave in *w*, then the optimal access charge $\widehat{w}^f$ selected by the regulator at the equilibrium is given by the first-order condition $\frac{\partial W(\widehat{x}(w),w)}{\partial w} = 0$. By inserting for $\widehat{x}(w)$ and $\widehat{w}^f$ in constraints $1 \geq \hat{s}(x,w) \geq \bar{s}(x,w) \geq 0$, we find that $\widehat{x}(w)$ and $\widehat{w}^f$ are feasible iff $2/3 < \beta \leq \beta^f(\gamma) = \sqrt{\frac{\gamma\left(80 - 12\gamma + 8\gamma^2 + 6\gamma^3 - \gamma^4 + \sqrt{4096 - 256\gamma + 2240\gamma^2 + 384\gamma^3 - 4\gamma^4 + 132\gamma^5 - 28\gamma^6 - 4\gamma^7 + \gamma^8}\right)}{72 + 56\gamma + 18\gamma^2 + 12\gamma^3 + 4\gamma^4}}$.

Let us consider now the cases where either $\bar{s}\left(\widehat{x}\left(\widehat{w}^f\right), \widehat{w}^f\right) \geq 0$ or $\hat{s}\left(\widehat{x}\left(\widehat{w}^f\right), \widehat{w}^f\right) \geq \bar{s}\left(\widehat{x}\left(\widehat{w}^f\right), \widehat{w}^f\right)$ does not hold. The latter constraint is always satisfied, while $\bar{s}\left(\widehat{x}\left(\widehat{w}^f\right), \widehat{w}^f\right) < 0$ (i.e. $\widehat{x}\left(\widehat{w}^f\right) > \frac{2\widehat{w}^f + \gamma + \gamma \cdot \widehat{w}^f - \gamma^2}{\beta(\gamma+2)}$) iff $\beta^f(\gamma) < \beta < 1$. In this case, we find the optimal quality investment by solving the equation $\bar{s}(x,w) = 0$, and obtain $\bar{x}(w) = \frac{2w + \gamma + \gamma \cdot w - \gamma^2}{\beta(\gamma+2)}$. Since the welfare function $W(\bar{x}(w), w)$ is strictly concave in *w*, then the access charge $\bar{w}^f$ selected by the regulator at the equilibrium is given by the first-order condition $\frac{\partial W(\bar{x}(w), w)}{\partial w} = 0$. By inserting for $\bar{x}(w)$ and $\bar{w}^f$ in constraints $1 \geq \hat{s}(x,w) \geq \bar{s}(x,w) \geq 0$, we find that $\bar{x}(w)$ and $\bar{w}^f$ are feasible iff $\beta^f(\gamma) < \beta < 1$.■

Proof of Proposition 3. Let solve the game backwards. Since, downstream firms *i* and *e* are identical, the retail price selected by downstream firms at the third stage of the game are equal to the wholesale access charge (Bertrand competition), that is, $\widehat{p}_i(x,w) = \widehat{p}_e(x,w) = w$; thus, the marginal consumer is equal to $\frac{w - \beta \cdot x}{\gamma}$. Inserting for $\widehat{p}_i(x,w)$ and $\widehat{p}_e(x,w)$, the model validity constraints $1 \geq \hat{s}(x,w) \geq \bar{s}(x,w) \geq 0$ are satisfied in the following cases: (i) when $0 \leq w \leq \gamma$ and $0 \leq x \leq \frac{w}{\beta}$, (ii) when $w > \gamma$ and $\frac{w-\gamma}{\beta} \leq x \leq \frac{w}{\beta}$. In the remaining cases, either

$\bar{s}(x,w) \geq 0$ or $\bar{s}(x,w) \leq 1$ does not hold ($\bar{s}(x,w) < 0$ when $x > \frac{w}{\beta}$); $\bar{s}(x,w) > 1$ when $w > \gamma$ and $0 \leq x < \frac{w-\gamma}{\beta}$).

At the second stage, firm *a* maximizes its profit $\pi_a(x,w)$ with respect to quality investment. The profit function is strictly concave in *x*. Hence, by the first-order condition on firm *a*'s profit we find the optimal investment $\widehat{x}(w) = \frac{\beta \cdot w}{\gamma}$. Since the welfare function $W(\widehat{x}(w), w)$ is strictly concave in *w*, then the optimal access charge $\widehat{w}^s$ selected by the regulator at the equilibrium is given by the first-order condition $\frac{\partial W(\widehat{x}(w), w)}{\partial w} = 0$. By inserting for $\widehat{x}(w)$ and $\widehat{w}^s$ in constraints $1 \geq \hat{s}(x,w) \geq \bar{s}(x,w) \geq 0$, we find that $\widehat{x}(w)$ and $\widehat{w}^s$ are feasible iff $2/3 < \beta \leq \beta^s(\gamma)$.

Let us consider now the cases where either $\bar{s}(\widehat{x}(\widehat{w}^s), \widehat{w}^s) \geq 0$ or $\bar{s}(\widehat{x}(\widehat{w}^s), \widehat{w}^s) \leq 1$ does not hold. The latter constraint is always satisfied, while $\bar{s}(\widehat{x}(\widehat{w}^s), \widehat{w}^s) < 0$ (i.e. $\widehat{x}(\widehat{w}^s) > \frac{\widehat{w}^s}{\beta}$) iff $\beta^s(\gamma) < \beta < 1$. In this case, we find the optimal quality investment by solving the equation $\bar{s}(x,w) = 0$, and obtain $\bar{x}(w) = \frac{w}{\beta}$. Since the welfare function $W(\bar{x}(w), w)$ is strictly concave in *w*, then the access charge $\overline{w}^s$ selected by the regulator at the equilibrium is given by the first-order condition $\frac{\partial W(\bar{x}(w), w)}{\partial w} = 0$. By inserting for $\bar{x}(w)$ and $\overline{w}^s$ in constraints $1 \geq \hat{s}(x,w) \geq \bar{s}(x,w) \geq 0$, we find that $\bar{x}(w)$ and $\overline{w}^s$ are feasible iff $\beta^s(\gamma) < \beta < 1$.■

Tables

The following tables summarize the outcomes of the game respectively under vertical integration, functional separation and structural separation, in terms of firms' market shares, quality investment, access charge and social welfare.

$\frac{2}{3} < \delta < \delta^I(\gamma)$	$\delta^I(\gamma) \le \delta < 1$
$\hat{q}_i^I = 1$	$\overline{q}_i^I = \frac{\gamma^2(2+\gamma) - 3\gamma\delta + 2(1+\gamma)\delta^2 - 2(1+\delta)}{3\gamma^2 + \gamma^3 + 2\gamma(-1+\delta)^2 + 3(-2+\delta)\delta - 1}$
$\hat{q}_e^I = 0$	$\overline{q}_e^I = \frac{(\gamma+1)^2 - (4+\gamma)\delta + \delta^2}{3\gamma^2 + \gamma^3 + 2\gamma(-1+\delta)^2 + 3(-2+\delta)\delta - 1}$
$\hat{x}^I = \frac{1-\gamma}{1-\delta}$	$\overline{x}^I = \frac{(\gamma-1)(3+\delta+\gamma(3+\gamma+\delta))}{3\gamma^2 + \gamma^3 + 2\gamma(-1+\delta)^2 + 3(-2+\delta)\delta - 1}$
$\hat{w}^I = \frac{(1-\gamma)\delta}{1-\delta}$	$\overline{w}^I = \frac{(\gamma-1)\left(\gamma(1+\gamma)^2 - (-3+\gamma)\delta + (1+2\gamma)\delta^2\right)}{3\gamma^2 + \gamma^3 + 2\gamma(-1+\delta)^2 + 3(-2+\delta)\delta - 1}$
$\hat{W}^I = \frac{2-\gamma^2 + 2\gamma\delta + (\delta-4)\delta}{(1-\delta)^2}$	$\overline{W}^I = \frac{2\gamma^3 + 2(-3+\delta)\delta + \gamma^2(5+2\delta) + \gamma(1+3(-2+\delta)\delta) - 3}{2\left(-1+3\gamma^2 + \gamma^3 + 2\gamma(-1+\delta)^2 + 3(-2+\delta)\delta\right)}$

Table 1. Vertical integration – outcome of the game.

$\frac{2}{3} < \beta \le \beta^f(\gamma)$	$\beta^f(\gamma) < \beta < 1$
$\hat{q}_i^f = \frac{-2\gamma^2(-4+\gamma)^2(1+2\gamma)-\beta^4(2+\gamma)(-12+\gamma(2+\gamma))+\gamma\beta^2(-64+\gamma(40+\gamma(4-7\gamma)))}{-\gamma^2(-4+\gamma)^2(4+5\gamma)+\beta^4(48+28\gamma+3\gamma^3+2\gamma^4)+\gamma\beta^2(-128+\gamma(64+\gamma(-4+\gamma(-14+\gamma))))}$	$\bar{q}_i^f = \frac{1+\gamma}{2+\gamma}$
$\hat{q}_e^f = \frac{3\gamma^2(-4+\gamma)^2+\gamma\beta^2(-4+\gamma)(2+\gamma)^2+\beta^4(2+\gamma)(6+\gamma+2\gamma^2)}{-\gamma^2(-4+\gamma)^2(4+5\gamma)+\beta^4(48+28\gamma+3\gamma^3+2\gamma^4)+\gamma\beta^2(-128+\gamma(64+\gamma(-4+\gamma(-14+\gamma))))}$	$\bar{q}_e^f = \frac{1}{2+\gamma}$
$\hat{x}^f = \frac{\gamma\beta(-4\gamma(-4+\gamma)(-1+\gamma)^2-\beta^2(72+\gamma(2+\gamma)(-2+5\gamma)))^2}{-\gamma^2(-4+\gamma)^2(4+5\gamma)+\beta^4(48+28\gamma+3\gamma^3+2\gamma^4)+\gamma\beta^2(-128+\gamma(64+\gamma(-4+\gamma(-14+\gamma))))}$	$\bar{x}^f = \beta$
$\hat{w}^f = \frac{\gamma(-4\gamma^2(-4+\gamma)^2(-1+\gamma)-\gamma\beta^2(80+\gamma(-2+\gamma)(-10+9\gamma))-2\beta^4(12+\gamma(-14+\gamma+\gamma^2)))}{-\gamma^2(-4+\gamma)^2(4+5\gamma)+\beta^4(48+28\gamma+3\gamma^3+2\gamma^4)+\gamma\beta^2(-128+\gamma(64+\gamma(-4+\gamma(-14+\gamma))))}$	$\bar{w}^f = -3+\beta^2+\gamma+\frac{6}{2+\gamma}$
$\hat{W}^f = \frac{-3\gamma^2(-4+\gamma)^2(1+2\gamma)-\beta^4(-1+\gamma)(36+\gamma^2(5+4\gamma))+\gamma\beta^2(-96+\gamma(20+\gamma(-6+\gamma(3-2\gamma))))}{2(-\gamma^2(-4+\gamma)^2(4+5\gamma)+\beta^4(48+28\gamma+3\gamma^3+2\gamma^4)+\gamma\beta^2(-128+\gamma(64+\gamma(-4+\gamma(-14+\gamma)))))}$	$\bar{W}^f = \frac{3+\beta^2(2+\gamma)^2+\gamma(5+\gamma)}{2(2+\gamma)^2}$

Table 2. Functional separation – outcome of the game.

$\frac{2}{3} < \beta \le \beta^s(\gamma)$	$\beta^s(\gamma) < \beta < 1$
$\hat{q}_i^s + \hat{q}_e^s = \frac{\gamma^2}{-\beta^4 + \gamma \cdot \beta^2 + \gamma^2}$	$\overline{q}_i^s + \overline{q}_e^s = 1$
$\hat{x}^s = \frac{\gamma \cdot \beta^3}{-\beta^4 + \gamma \cdot \beta^2 + \gamma^2}$	$\overline{x}^s = \beta$
$\hat{w}^s = \frac{\gamma^2 \cdot \beta^2}{-\beta^4 + \gamma \cdot \beta^2 + \gamma^2}$	$\overline{w}^s = \beta^2$
$\hat{W}^s = \frac{\gamma^2(\gamma + \beta^2)}{2(-\beta^4 + \gamma \cdot \beta^2 + \gamma^2)}$	$\overline{W}^s = \frac{1}{2}(\gamma + \beta^2)$

Table 3. Structural separation – outcome of the game.

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