Make-or-buy investment decisions in copper and fiber access markets

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Abstract

This paper studies the optimal regulatory policy that should be implemented during the transition from copper to fiber access networks when the entrant undertakes a "make-or-buy" investment decision. Three different types of competition may arise: service-based competition over copper access networks, service-based competition over fiber access networks and facilities-based competition over fiber access networks. The particular value of the investment cost parameter determines the socially optimal type of competition. The regulator can induce the entrant to undertake the socially optimal "make-or-buy" decision by setting suitable access schemes. In particular, whenever service-based competition is socially optimal, the regulator should set the welfare-maximizing access price (or the highest possible one that does not distort the entrant's decision) to the network over which service-based competition leads to higher welfare levels, as well as set the access price to the other network at the level that makes the entrant exit the respective market. On the contrary, whenever facilities-based competition is socially optimal, the regulator should ban access to the incumbent's upstream facilities in order to induce the entrant to invest in its own fiber access infrastructures.

Key Words: access regulation; make-or-buy decisions; fiber investments.

JEL Classification: L51, L96.

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1 Introduction

The relationship between access regulation and investment in new fiber access infrastructures (the so-called Next Generation Access Networks) has been at the core of the policy debate since the realization that the legacy copper access networks would be incapable of meeting the end-users' future demand for bandwidth. In addition, investment in fiber access networks has also attracted the interest of national governments since higher speed broadband services increase the positive impact of broadband on economic growth, productivity at the firm level, employment growth and consumers' welfare (Czernich, Falck, Kretschmer, & Woessmann, 2011; ITU, 2012; Katz, Vaterlaus, Zenhausern, & Suter, 2010). Given that the social benefits from investment in digital infrastructures by far exceed the private incentive for investment (European Commission, 2011), the role of regulatory intervention seems to be very crucial for achieving the goals of the Digital Agenda for Europe, which envisions that, by 2020, all Europeans will have access to internet connection speeds of at least 30Mbps, as well as internet speeds of 100 Mbps will be available to 50% or more of European households (European Commission, 2010).

In this context, a first strand of the related literature assesses the impact of cost-based regulation on firms' investment incentives as this type of intervention has been widely adopted for promoting competition within one network. It is generally found that such a regulatory policy stimulating efficient entry in the short-run also results in a substantial deviation from the socially desirable outcomes in terms of network deployment and timing of investment, thus implying significant losses in dynamic efficiency (Bouckaert, van Dijk, & Verboven, 2010).[1] For this reason, academic research has shifted its focus from studying the impact of cost-based regulation on static and dynamic efficiency to the design of new regulatory approaches that may promote both static efficiency and socially optimal investment in fiber access networks.[2] The main assumption of this literature is that the transition from copper to fiber access networks is an instant process meaning that the copper access networks are switched-off immediately after the fiber deployment.

However, as Bourreau, Cambini, & Hoernig (2012) point out, the migration from copper to fiber access networks is a slow process, during which both fiber access networks and existing copper infrastructures will coexist and compete for consumers. Such coexistence may stem from: (i) the deployment of fiber access infrastructures in some geographic areas, which implies that the copper access networks will be still in operation in the remaining geographic areas of a given country; or (ii) the ability of the non-investing firm to choose between using the old and the new technology.[3]

In the former case, Bourreau, Cambini, & Doğan (2012) study the impact

[1] See Cambini and Jiang (2009) for a review of this literature.

[2] See Tselekounis, Varoutas, & Martakos (2014) for a review of this literature.

[3] If the entrant is the non-investing firm, it can buy access to the incumbent's copper or fiber access networks, whereas if the incumbent is the non-investing firm, it may decide to continue using its copper infrastructures or to seek access to the entrant's fiber ones.

of the access price of copper unbundling on firms' incentives to extend their fiber deployment to more geographic areas. They show that a higher copper access price positively affects the incentives of the entrant to extend its fiber deployment to more geographic areas, whereas it has an ambiguous effect on the incumbent's investment in coverage. On the contrary, Lestage & Flacher (2010) study the impact of the access price of fiber unbundling on the decision of firms to invest in coverage of fiber access networks. They point out that access regulation (and especially marginal cost pricing) improves social welfare in covered areas, but it extends the region where none of the firms is willing to roll out fiber access networks and reduces the geographic areas where facilities-based competition arises. Last, Bourreau, Cambini, & Doğan (2014) study the effect of the access prices of both copper and fiber unbundling on firms' incentives to invest in fiber coverage. They find that when the global coverage is determined by the fiber deployment of the incumbent (respectively, the entrant), the socially optimal access price to its fiber network is positively (respectively, negatively) correlated with the access price to the copper network. The main policy implication is that regulators cannot treat the two access prices independently.

In the latter case, Brito, Pereira, & Vareda (2012) focus on the impact of the access price to the copper network on firms' incentives to invest in an exogenously given quality. This implies that the fiber investment cost is fixed and firms decide whether to invest or not in any given market. They find that the regulator sets the access price for the copper network at marginal cost as long as the investment in quality by the incumbent is small. Otherwise, the regulator sets a high copper access price. This regulatory policy leads to the socially desirable market structure since the fiber market is a duopoly in the former case and a monopoly in the latter one. Most significantly, they also show that when both firms can invest in fiber access networks, the regulator cannot influence the equilibrium of the game.

Notice that the above-cited papers considering that both technologies will coexist for a certain period of time also assume that: (i) the quality of the fiber access network is exogenous (regardless of whether firms invest in quality or coverage); and (iii) when an operator invests in fiber access networks, that firm no longer provides the lower quality (e.g., basic broadband) services.

This paper contributes to the literature studying the optimal regulatory policy during the gradual transition from copper to fiber access networks when the investing firm no longer provides the lower quality services by considering that the investment in quality is continuous and firms endogenously decide their optimal quality investment level.[4] In addition, contrary to the incumbent who is always assumed to invest in fiber access infrastructures, the entrant endogenously chooses between investing in its own fiber access network (facilities-based competition) and seeking access (service-based competition) to either the copper or the fiber access network of the incumbent. In this sense, this paper bridges the literature on the optimal regulatory policy during a gradual transition phase

[4] See Bourreau, Lupi, & Manenti (2014), Brito & Tselekounis (2015) and Flacher & Jennequin (2014) for the the optimal access regulation policy during migration from copper to fiber access networks when firms are engaged in multi-product competition.

and the literature studying the efficiency implications of the effect of the access prices on an entrant's "make-or-buy" decision (Gayle & Weisman, 2007; Mandy, 2008; Sappington, 2005; Tselekounis, Varoutas, & Martakos, 2012). Contrary to the latter literature in which the "buy" decision refers to a single available market and the "make" decision does not require any investment in quality, this paper is the first considering that the option to "buy" may allow the access seeker to choose between using the old and the new technology, as well as that the option to "make" may require an investment in quality which incurs an investment cost.

It is found that different types of competition (i.e., facilities-based competition and service-based competition over the copper or the fiber access network of the incumbent) may arise depending on the parameter affecting the investment cost. The regulator can induce the welfare maximizing type of competition by suitably setting the access prices to the copper and fiber access networks whenever a type of service-based competition is socially optimal and by banning access to the incumbent's access infrastructures whenever facilities-based competition is socially optimal.

The rest of the paper is organized as follows. Section 2 presents the modeling setup. Section 3 characterizes the equilibrium of the game and presents the optimal regulatory intervention. Section 4 analyzes the main findings from a social and an investment perspective. The final section concludes.

2 The Model

At the beginning of the game, an incumbent (firm 1) and an entrant (firm 2) compete for providing a basic broadband service over the copper access network of the incumbent (network C), which is the upstream monopolist. The deployment of a fiber access network (network F) capable of providing ultra-fast broadband services is an upgrade of the copper access network.

Deploying a fiber access network of quality δ incurs a quadratic fiber investment cost $c(\delta) = k(\delta_i)^2/2$, with $i = 1, 2$ and $k > 0$. The investment in quality is continuous where higher values of δ mean that the fiber deployment is closer to the consumers' premises, which translates into faster broadband services. The investment cost parameter k reflects the rate at which the fiber investment cost becomes marginally more expensive as it approaches the consumers' premises. When a firm invests in the fiber access network, it no longer employs the copper access network to provide its services (i.e., the new technology replaces the old one).

Firms may have incentives to deploy a fiber access network since consumers value the ultra-fast broadband services provided over that network more than those provided over the copper network. This situation can be modeled by the competitive setting of Katz and Shapiro (1985). In particular, the indirect utility function of a consumer of type τ is

$$U = \tau + \delta_i - p_i$$

where p_i denotes the price of the firm i, with $i = 1, 2$. Consumers are uniformly distributed in $[-\infty, 1]$. This competitive setting has been already used by the research papers focusing on the decision of an incumbent and an entrant to invest in fiber coverage (e.g., Bourreau, Cambini, & Doğan, 2010 & 2012) assuming exogenously given quality levels for the fiber (δ_f) and the copper (δ_c) access networks, with $\delta_f > \delta_c$. On the contrary, this paper focuses on a single geographic market but allows the incumbent and the entrant to endogenously choose their fiber quality level, with $\delta_c = 0$ and $\delta_f = \delta_i$, $i = 1, 2$.

The type of competition between the incumbent and the entrant is determined before the fiber deployment. The reason is that the entrant has to make a long-run strategic "make-or-buy" decision concerning the way to reach its consumers. In particular, the entrant has three options:

(i) it may choose to reach its consumers without asking access to the incumbent's upstream facilities, thus it has to deploy its own fiber access network characterized by the fiber quality δ_2. In this case, facilities-based competition is established and no access price regulation takes place;

(ii) it may choose to use the incumbent's fiber access network to reach its consumers and thus offer them the higher quality (i.e., ultra-fast) broadband services. In this case, service-based competition over fiber access networks is established and the entrant has to lease the incumbent's fiber upstream facilities at a per-unit access price, $a_f > 0$;

(iii) it may choose to use the incumbent's copper access network to reach its consumers and thus offer them the lower quality (i.e., basic) broadband services. In this case, service-based competition over copper access networks is established and the entrant has to lease the incumbent's copper upstream facilities at a per-unit access price, $a_c > 0$.

It is assumed that the entrant can credibly commit to its decision, meaning that the entrant is not allowed to have access to an incumbent's access network once it has chosen to be a facilities-based competitor. It is further assumed that the incumbent cannot degrade the quality of the services it sells to the entrant, meaning that, whenever the incumbent is an upstream monopolist, the quality of the services of both firms is the same. Last, the marginal cost of providing access to each network and delivering each final service to the consumers is the same for the two firms and is normalized to zero.

After the entrant has made its "make-or-buy" decision, the incumbent chooses its optimal investment in fiber quality denoted by δ_1. If the entrant has decided to be a facilities-based competitor, it chooses its optimal investment in fiber quality after the incumbent's investment decision. The assumption about sequential investment decision is common in the related literature and it reflects the fact that the incumbent firm typically faces some specific advantages due to its control over the existing infrastructure and ducts that facilitate the deployment of the new infrastructure (Bourreau, Cambini, & Doğan, 2012).

The timing of the game is as follows: The regulator commits to the access scheme that maximizes social welfare. The available regulatory schemes span from setting the access prices for copper and fiber unbundling to banning access to the incumbent's upstream facilities. Then, the entrant decides how to reach its consumers by making its “make-or-buy” decision. Having observed the entrant’s “make-or-buy” decision, the incumbent chooses its optimal fiber investment level. If the entrant has decided to be a facilities-based competitor, it chooses its optimal investment in fiber quality after observing the incumbent’s fiber deployment. Finally, firms compete in quantities in the market of broadband services.

3 The equilibrium

In this section, we characterize the equilibrium of the game which is solved backwards. Hence, we first solve the retail competition stage for each option of the entrant’s "make-or-buy" decision. Given the equilibrium retail outcomes, we calculate the profit-maximizing investment level of the entrant (in the case it chooses to invest in fiber upstream facilities) and then that of the incumbent. Afterwards, we present the entrant’s decision on how to reach consumers and finally, we analyze the regulator’s decision with respect to the access schemes.

3.1 Retail competition stage

In this stage, the equilibrium retail outcomes are derived for each option of the entrant’s "make-or-buy" decision. This decision also determines the type of competition that prevails in the market. Regardless of the type of competition, the two firms are both active in the market as long as their quality-adjusted prices are the same, that is $p_1 - \delta_1 = p_2 - \delta_2 = P$. The marginal consumer has valuation $\tau = P$, and hence, the total demand is given by $Q = q_1 + q_2 = 1 - P$ due to the uniform distribution of consumers. Notice that when the entrant seeks access to the incumbent’s copper (respectively, fiber) access network, then $\delta_2 = 0$ (respectively, $\delta_2 = \delta_1$).

3.1.1 Facilities-based competition over fiber access networks (*FF*)

When the entrant decides to deploy its own fiber access network, the retail price set by each firm can be written as

$$\begin{aligned} p_1^{FF} &= 1 + \delta_1^{FF} - \left(q_1^{FF} + q_2^{FF}\right) \\ p_2^{FF} &= 1 + \delta_2^{FF} - \left(q_1^{FF} + q_2^{FF}\right) \end{aligned}$$

In addition, the profit functions of the incumbent and the entrant are given, respectively, by

$$\begin{aligned} \pi_1^{FF} &= p_1^{FF} q_1^{FF} - \frac{k(\delta_1^{FF})^2}{2} \\ \pi_2^{FF} &= p_2^{FF} q_2^{FF} - \frac{k(\delta_2^{FF})^2}{2} \end{aligned}$$

Substituting the retail prices into the profit functions and solving the system of the first-order conditions with respect to the quantities gives the equilibrium output of each firm:

$$\begin{aligned} q_1^{FF} &= \frac{1+2\delta_1^{FF}-\delta_2^{FF}}{3} \\ q_2^{FF} &= \frac{1+2\delta_2^{FF}-\delta_1^{FF}}{3} \end{aligned}$$

Note that both firms are active in the market as long as

$$\begin{aligned} 1+2\delta_1^{FF}-\delta_2^{FF} &> 0 \\ 1+2\delta_2^{FF}-\delta_1^{FF} &> 0 \end{aligned}$$

Therefore, the total profit of the incumbent and the entrant are given, respectively, by

$$\begin{aligned} \pi_1^{FF} &= \frac{\left(1+2\delta_1^{FF}-\delta_2^{FF}\right)^2}{9} - \frac{k}{2}\left(\delta_1^{FF}\right)^2 \\ \pi_2^{FF} &= \frac{\left(1+2\delta_2^{FF}-\delta_1^{FF}\right)^2}{9} - \frac{k}{2}\left(\delta_2^{FF}\right)^2 \end{aligned}$$

3.1.2 Service-based competition over copper access networks (SC)

In this case, the entrant decides to lease the incumbent's copper access network at a per-unit access price, $a_c > 0$. This means that the entrant avoids the fiber investment cost, but it provides its consumers with the basic broadband services. The profit functions of the incumbent and the entrant are given, respectively, by

$$\begin{aligned} \pi_1^{SC} &= p_1^{SC}q_1^{SC} + a_c q_2^{SC} - \frac{k(\delta_1^{SC})^2}{2} \\ \pi_2^{SC} &= \left(p_2^{SC} - a_c\right) q_2^{SC} \end{aligned}$$

Given that $\delta_2^{SC} = 0$, the equilibrium output and profit of each firm are given by

$$\begin{aligned} q_1^{SC} &= \frac{1+2\delta_1^{SC}+a_c}{3} \\ q_2^{SC} &= \frac{1-\delta_1^{SC}-2a_c}{3} \end{aligned}$$

and

$$\pi_1^{SC} = \frac{2 + 10a_c(1 - a_c) + 2a_c\delta_1^{SC} + 8\delta_1^{SC}\left(1 + \delta_1^{SC}\right) - 9k(\delta_1^{SC})^2}{18}$$

$$\pi_2^{SC} = \frac{\left(1 - \delta_1^{SC} - 2a_c\right)^2}{9}$$

Note that both firms are active in the market as long as $\left(1 - \delta_1^{SC} - 2a_c\right) > 0$.

3.1.3 Service-based competition over fiber access networks (*SF*)

In this case, the entrant supplies its consumers with the ultra-fast broadband services by leasing the incumbent's fiber access network at a per-unit access price, $a_f > 0$, rather than investing in its own fiber access facilities. This means that both firms provide the same quality services ($\delta_1^{SF} = \delta_2^{SF}$), but the incumbent bears the whole investment cost alone and, in exchange, it receives an access price for leasing its infrastructures. The profit functions of the incumbent and the entrant are given, respectively, by

$$\pi_1^{SF} = p_1^{SF}q_1^{SF} + a_f q_2^{SF} - \frac{k(\delta_1^{SF})^2}{2}$$

$$\pi_2^{SF} = \left(p_2^{SF} - a_f\right)q_2^{SF}$$

In this case, the equilibrium output and profit of each firm are given by

$$q_1^{SF} = \frac{1 + \delta_1^{SF} + a_f}{3}$$

$$q_2^{SF} = \frac{1 + \delta_1^{SF} - 2a_f}{3}$$

and

$$\pi_1^{SF} = \frac{2 + 10a_f\left(1 + \delta_1^{SF} - a_f\right) + 2\delta_1^{SF}\left(\delta_1^{SF} + 2\right) - 9k(\delta_1^{SF})^2}{18}$$

$$\pi_2^{SF} = \frac{\left(1 + \delta_1^{SF} - 2a_f\right)^2}{9}$$

Note that both firms are active in the market as long as $\left(1 + \delta_1^{SF} - 2a_f\right) > 0$.

3.2 The entrant's investment decision

If the entrant has decided to be a facilities-based competitor, its optimal investment in fiber quality is chosen in this stage. Otherwise, this stage does not exist.

The entrant's privately optimal investment level is derived by solving the first-order condition of π_2^{FF} with respect to δ_2^{FF}. Therefore,

$$\delta_2^{FF} = \frac{4\left(1-\delta_1^{FF}\right)}{(9k-8)}$$

The respective second-order condition requires $(9k-8) > 0 \Rightarrow k > 8/9$, whereas $\delta_2^{FF} > 0$ if $\delta_1^{FF} < 1$. It is interesting to point out that the entrant's fiber investment level is negatively correlated with the incumbent's one. This means that whenever the incumbent increases its fiber deployment, the entrant decreases its fiber investment in reaction. Substituting the derived level of δ_2^{FF} into the firms' profit functions yields

$$\begin{aligned}
\pi_1^{FF} &= \frac{\begin{array}{c}32+\left(32-81k^3+216k^2-160k\right)\left(\delta_1^{FF}\right)^2 \\ +8\,(3k-2)\,(3k-4)\,\delta_1^{FF}-6k\,(8-3k)\end{array}}{2\,(9k-8)^2} \\
\pi_2^{FF} &= \frac{k\left(1-\delta_1^{FF}\right)^2}{(9k-8)}
\end{aligned}$$

3.3 The incumbent's investment decision

In this stage, the incumbent decides its optimal investment in fiber quality according to the type of competition triggered by the entrant's "make-or-buy" decision. Therefore, as in the "retail competition stage", three different cases are considered.

3.3.1 Facilities-based competition over fiber access networks (*FF*)

The incumbent's privately optimal investment level is derived by solving the first-order condition of π_1^{FF} with respect to δ_1^{FF}. Therefore,

$$\delta_1^{FF} = \frac{4\,(3k-2)\,(3k-4)}{(160k-216k^2+81k^3-32)}$$

Given that $k > 8/9$, the respective second-order condition requires the denominator of δ_1^{FF} to be positive, which also ensures that $\delta_1^{FF} > 0$ since $\left(160k-216k^2+81k^3-32\right) > 0$ when $k > 1.5670$. Therefore, the entrant's privately optimal investment level is

$$\delta_2^{FF} = \frac{4\left(9k^2-20k+8\right)}{(160k-216k^2+81k^3-32)}$$

As a result, the profit of the incumbent and the entrant under FF are

$$\pi_1^{FF} = \frac{(3k-4)^2 k}{(160k - 216k^2 + 81k^3 - 32)}$$
$$\pi_2^{FF} = \frac{\left(9k^2 - 20k + 8\right)^2 (9k-8) k}{(160k - 216k^2 + 81k^3 - 32)^2}$$

whereas their outputs are given by

$$q_1^{FF} = \frac{(3k-4)(9k-8) k}{(160k - 216k^2 + 81k^3 - 32)}$$
$$q_2^{FF} = \frac{3\left(9k^2 - 20k + 8\right) k}{(160k - 216k^2 + 81k^3 - 32)}$$

As a result, the entrant is active in the market as long as $\left(9k^2 - 20k + 8\right) > 0 \Rightarrow k > 1.6991$.

3.3.2 Service-based competition over copper access networks (SC)

The incumbent's privately optimal investment level is derived by solving the first-order condition of π_1^{SC} with respect to δ_1^{SC}. Therefore,

$$\delta_1^{SC} = \frac{4 + a_c}{9k - 8}$$

Given that $k > 8/9$, the respective second-order condition is satisfied and the incumbent always chooses a positive fiber investment level. The profit functions of the incumbent and the entrant under SC are

$$\pi_1^{SC} = \frac{(9-10k) a_c^2 + 2(5k-4) a_c + 2k}{2(9k-8)}$$
$$\pi_2^{SC} = \frac{(3k - 4 - (6k-5) a_c)^2}{(9k-8)^2}$$

whereas their outputs are given by

$$q_1^{SC} = \frac{(3k - 2a_c + 3ka_c)}{(9k-8)}$$
$$q_2^{SC} = \frac{3k - 4 - (6k-5) a_c}{(9k-8)}$$

As a result, both firms are active in the market as long as $a_c < \frac{3k-4}{6k-5}$.

3.3.3 Service-based competition over fiber access networks (SF)

In this case, the incumbent's privately optimal investment level is derived by solving the first-order condition of π_1^{SF} with respect to δ_1^{SF}. Therefore, if the entrant has chosen to buy access to the incumbent's fiber access network, the latter's optimal investment level is

$$\delta_1^{SF} = \frac{2 + 5a_f}{9k - 2}$$

Given that $k > 2/9$, the respective second-order condition is satisfied and the incumbent always chooses a positive fiber investment level. The profit of the incumbent and the entrant under SF are

$$\begin{aligned} \pi_1^{SF} &= \frac{-5(2k-1)a_f^2 + 10ka_f + 2k}{2(9k-2)} \\ \pi_2^{SF} &= \frac{9(a_f - 2ka_f + k)^2}{(9k-2)^2} \end{aligned}$$

whereas their outputs are given by

$$\begin{aligned} q_1^{SF} &= \frac{(3k + a_f + 3ka_f)}{(9k-2)} \\ q_2^{SF} &= \frac{3(a_f - 2ka_f + k)}{(9k-2)} \end{aligned}$$

As a result, both firms are active in the market as long as $a_f < \frac{k}{2k-1}$.

3.4 The entrant's "make-or-buy" decision

In this stage, the entrant decides how to reach its consumers by undertaking its “make-or-buy” decision. The option to "make" requires an investment in fiber quality which incurs an investment cost. In this case, the entrant is a facilities-based competitor, and hence, the entrant's profit is given by π_2^{FF}. On the contrary, the option to "buy" allows the entrant to decide to use either the copper or the fiber access network of the incumbent, thus providing its consumers with the respective broadband service. In the former (respectively, latter) case, the entrant is a service-based competitor over copper (respectively, fiber) access networks, and hence, the entrant's profit is given by π_2^{SC} (respectively, π_2^{SF}).

Before proceeding to the discussion of the entrant's "make-or-buy" decision, the following assumption is made:

Assumption 1. *Let* $k > 1.6991$, $a_c < \frac{3k-4}{6k-5}$ *and* $a_f < \frac{k}{2k-1}$.

Assumption 1 ensures that all second-order conditions hold, as well as both firms are active in the market regardless of the type of competition induced by the entrant's "make-or-buy" decision.

The entrant chooses to be a service-based competitor over copper access networks if $\pi_2^{SC} > \pi_2^{FF}$ and $\pi_2^{SC} > \pi_2^{SF}$. All profit functions have been written assuming positive quantities, thus the solution of $\pi_2^{SC} = \pi_2^{FF}$ returns one value of a_c, namely $\widehat{a_c}(k)$, which satisfies that $\widehat{a_c}(k) < \frac{3k-4}{6k-5}$, where

$$\widehat{a_c} = \frac{3k-4}{(6k-5)} - \frac{(9k-8)\left(9k^2-20k+8\right)\sqrt{(9k-8)\,k}}{(160k-216k^2+81k^3-32)\,(6k-5)}$$

Therefore, $\pi_2^{SC} > \pi_2^{FF}$ as long as $a_c < \widehat{a_c}$. It should be noted that $\widehat{a_c}$ is a decreasing function of k, as well as that $\widehat{a_c} = 0$ when $k = 1.8239$. This means that when $k > 1.8239$, then the entrant never chooses to seek access to the incumbent's copper upstream facilities since at least one alternative (i.e., the FF case) results in higher profit for the entrant. On the contrary, when $k < 1.8239$ and $a_c < \widehat{a_c}$, then the entrant chooses to be a service-based competitor either over copper or fiber access network depending on the comparison of π_2^{SC} and π_2^{SF}. In particular, the entrant decides to buy copper access from the incumbent when $a_c < \widetilde{a_c}(k, a_f)$, where

$$\widetilde{a_c} = \frac{3\,(2k-1)\,(9k-8)}{(9k-2)\,(6k-5)}a_f + \frac{8-18k}{(9k-2)\,(6k-5)}$$

On the other hand, the entrant is better off by leasing the incumbent's fiber access facilities when $\pi_2^{SF} > \pi_2^{SC}$ and $\pi_2^{SF} > \pi_2^{FF}$. The first inequality holds when $a_c > \widetilde{a_c}(k, a_f)$ or, equivalently, $a_f < \widetilde{a_f}(k, a_c)$, where

$$\widetilde{a_f}(k, a_c) = \left(a_c - \frac{8-18k}{(9k-2)\,(6k-5)}\right)\frac{(9k-2)\,(6k-5)}{3\,(2k-1)\,(9k-8)}$$

In addition, the entrant prefers SF to FF if $\pi_2^{SF} > \pi_2^{FF}$, which implies that $a_f < \widehat{a_f}(k)$, where

$$\widehat{a_f} < \frac{k}{(2k-1)} - \frac{(9k-2)\left(9k^2-20k+8\right)\sqrt{(9k-8)\,k}}{3\,(160k-216k^2+81k^3-32)\,(2k-1)}$$

It should be noted that $0 < \widehat{a_f} < \frac{k}{2k-1}$, which means that when $a_f \in [0, \widehat{a_f})$, the entrant is better off by being a service-based competitor over fiber access network than a facilities-based competitor, whereas the opposite result occurs as long as $a_f \in (\widehat{a_f}, \frac{k}{2k-1}]$.

Last, the entrant chooses to invest in its own fiber access networks when $\pi_2^{FF} > \pi_2^{SC}$ and $\pi_2^{FF} > \pi_2^{SF}$. Obviously, this outcome is equivalent to $a_c > \widehat{a_c}$ and $a_f > \widehat{a_f}$, provided that $a_c < \frac{3k-4}{6k-5}$ and $a_f < \frac{k}{2k-1}$.

In conclusion, the entrant's "make-or-buy" decision can be summarized in the following representative figure, which is qualitatively the same for any given value of k, but the exact curves of $\widehat{a_c}$, $\widehat{a_f}$ and $\widetilde{a_c}$ depend on the particular value of k.

From Figure 1, it is deduced that when both a_c and a_f are relatively high, the entrant chooses to deploy its own fiber access network. In addition, the entrant chooses to buy the incumbent's copper access infrastructures if a_c is

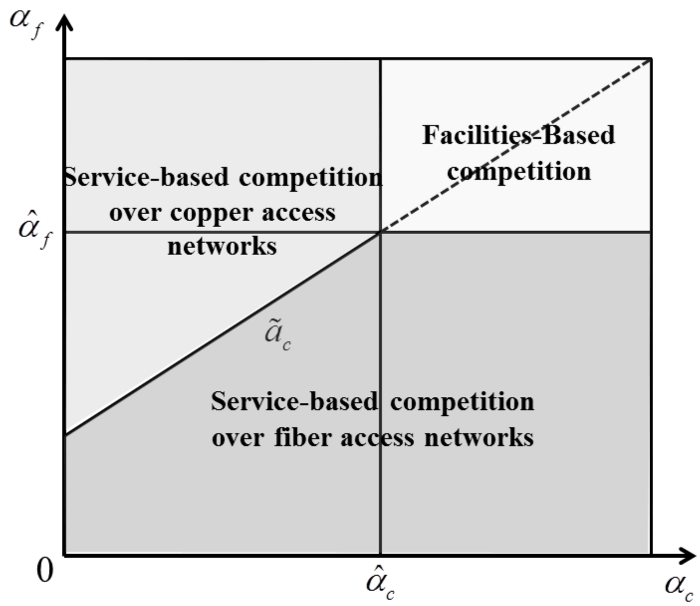

Figure 1: The entrant's "make-or-buy" decision

relatively low and a_f is relatively high. On the contrary, if a_f is quite low, the entrant chooses to buy the incumbent's fiber access infrastructures regardless of the established value of a_c, whereas as a_f increases, a higher a_c is required for making the entrant better off by buying fiber access.

3.5 The regulator's decision

This section initially presents the welfare-maximizing access pricing policy under each type of competition and then compares the derived social welfare levels so as to discuss the optimal regulatory scheme that should be implemented in order to induce the socially optimal outcome.

The goal of the sector-specific regulator is to maximize social welfare (SW) defined as the unweighted sum of industry profits and consumer surplus (CS). However, many components of the SW function are just transfers between the different parties of the society, and hence, they are irrelevant for social welfare. As a result, we can define SW as the total consumer valuation minus the total investment costs, where consumer valuation (CV) is given by

$$CV = \int_{1-q_1-q_2}^{1} t dt + q_1\delta_1 + q_2\delta_2 = \frac{2 - q_1 - q_2}{2}\left(q_1 + q_2\right) + q_1\delta_1 + q_2\delta_2$$

3.5.1 Facilities-based competition over fiber access networks (*FF*)

In this case, the incumbent and the entrant invest $\delta_1^{FF} = \frac{4(3k-2)(3k-4)}{(160k-216k^2+81k^3-32)}$ and, respectively, $\delta_2^{FF} = \frac{4\left(9k^2-20k+8\right)}{(160k-216k^2+81k^3-32)}$. Substituting these investment levels into the CV function and subtracting the total investment costs gives the total welfare under facilities-based competition over fiber access networks:

$$SW^{FF} = \frac{4\left(2008k - 5384k^2 + 6480k^3 - 3564k^4 + 729k^5 - 256\right)k}{\left(160k - 216k^2 + 81k^3 - 32\right)^2}$$

3.5.2 Service-based competition over copper access networks (*SC*)

In this case, the entrant leases the incumbent's copper upstream facilities (i.e., $\delta_2^{SC} = 0$), whereas the incumbent invests $\delta_1^{SC} = \frac{4+a_c}{9k-8}$. Therefore, social welfare is given by

$$SW^{SC} = \frac{\left(12 - 28k - 13a_c + 23ka_c + 18k^2 - 9k^2a_c\right)(4 + a_c)}{2\,(9k-8)^2}$$

It is obvious that SW^{SC} is independent of a_f, which means that whenever the regulator wants to induce *SC*, it will set $a_f > \widehat{a_f}$ in order to increase the range of a_c that leads the entrant to be a service-based competitor over copper access networks (see Figure 1). In particular, the regulator sets a_c at the level that maximizes social welfare. The first-order condition of SW^{SC} with respect to a_c gives

$$a_c^* = -\frac{\left(9k^2 - 32k + 20\right)}{\left(9k^2 - 23k + 13\right)}$$

However, the welfare-maximizing copper access price cannot be set since it is always higher than the critical value that makes the entrant be active in the market. Therefore, the regulator sets the highest possible level of a_c that makes the entrant choose to seek access to the incumbent's copper access infrastructures. This access price is $a_c = \widehat{a_c}$ and yields

$$SW^{SC} = \frac{\begin{pmatrix} \left(9k^2 - 9k + 1\right)\left(160k - 216k^2 + 81k^3 - 32\right) \\ + \left(\sqrt{9k^2 - 8k}\right)\left(9k^2 - 20k + 8\right)\left(9k^2 - 23k + 13\right) \end{pmatrix} \left((-3)\left(160k - 216k^2 + 81k^3 - 32\right) + \left(\sqrt{9k^2 - 8k}\right)\left(9k^2 - 20k + 8\right)\right)}{-2\left(160k - 216k^2 + 81k^3 - 32\right)^2 (6k-5)^2}$$

3.5.3 Service-based competition over fiber access networks (*SF*)

In this case, the entrant leases the incumbent's fiber upstream facilities (i.e., $\delta_1^{SF} = \delta_2^{SF}$), whereas the incumbent invests $\delta_1^{SF} = \frac{2+5a_f}{9k-2}$. Therefore, social welfare is given by

$$SW^{SF}=\frac{\left(-4k+64ka_f+72k^2+24a_f^2-31ka_f^2-18k^2a_f-9k^2a_f^2\right)}{2\left(9k-2\right)^2}$$

It is obvious that SW^{SF} is independent of a_c, which means that whenever the regulator wants to induce *SF*, it will set $a_c>\widehat{a_c}$ in order to increase the range of a_f that leads the entrant to be a service-based competitor over fiber access networks (see Figure 1). In particular, the regulator sets a_f at the level that maximizes social welfare. The first-order condition of SW^{SF} with respect to a_f gives

$$a_f^*=\frac{k\left(32-9k\right)}{31k+9k^2-24}$$

The regulator can set this fiber access price if it is lower than the critical value of a_f that leaves the entrant with zero output, as well as if it lower than $\widehat{a_f}$. It is found that a_f^* always satisfies the former condition, whereas $a_f^*<\widehat{a_f}$ when $k<1.7616$ and $k>3.1846$. In addition, note that $a_f^*<0$ when $k>32/9$, which means that for that range the regulator sets $a_f^*=0$.

In conclusion,

(i) when $k\in[1.6991,1.7616]$ or $k\in[3.1846,32/9]$, the regulator sets the socially optimal fiber access price and the derived social welfare level is

$$SW_{int}^{SF}=\frac{3\left(3k+8\right)k}{2\left(31k+9k^2-24\right)}$$

(ii) when $k\in[1.7616,3.1846]$, then $a_f^*>\widehat{a_f}$, and hence, the regulator sets the highest possible fiber access price that leads the entrant to buy fiber access from the incumbent. Therefore, $a_f^*=\widehat{a_f}$ and

$$SW_{cor}^{SF}=\frac{\left(\begin{array}{c}9216k-119\,808k^2+631\,296k^3-1733\,184k^4+2659\,392k^5\\-2274\,480k^6+1003\,833k^7-177\,147k^8-1536k\left(9k-8\right)\\+9664k^2\left(9k-8\right)-22\,400k^3\left(9k-8\right)+22\,624k^4\left(9k-8\right)\\-8208k^5\left(9k-8\right)-729k^6\left(9k-8\right)+729k^7\left(9k-8\right)\\-6144k\sqrt{k\left(9k-8\right)}+50\,688k^2\sqrt{k\left(9k-8\right)}\\-159\,744k^3\sqrt{k\left(9k-8\right)}+247\,680k^4\sqrt{k\left(9k-8\right)}\\-200\,880k^5\sqrt{k\left(9k-8\right)}+81\,648k^6\sqrt{k\left(9k-8\right)}\\-13\,122k^7\sqrt{k\left(9k-8\right)}\end{array}\right)}{-18\left(160k-216k^2+81k^3-32\right)^2\left(2k-1\right)^2}$$

(iii) when $k>32/9$, then $a_f^*<0$, and hence, the regulator sets $a_f^*=0$. In this case

$$SW_{zero}^{SF}=\frac{2\left(18k-1\right)k}{\left(9k-2\right)^2}$$

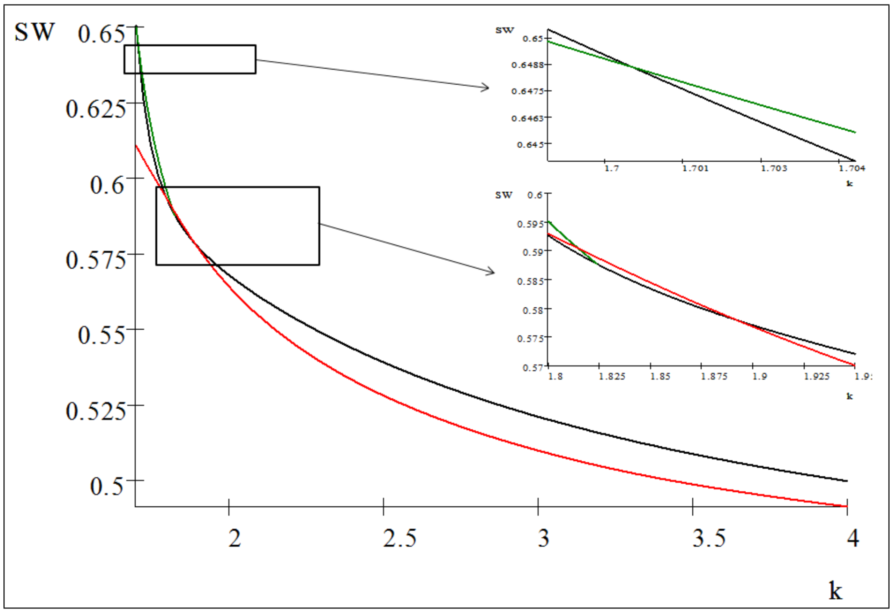

Figure 2: Social Welfare levels under *FF*, *SC* and *SF*

3.5.4 Optimal regulatory scheme

The regulator has to compare the levels of social welfare derived by each type of competition so as to choose the regulatory scheme resulting in the optimal outcome. Figure 2 plots the welfare functions corresponding to each type of competition for $k \in [1.6991, 4.0000]$. The black line represents the welfare derived by *FF* (SW^{FF}), the green line represents the welfare derived by *SC* (SW^{SC}) and the red line represents the welfare derived by *SF* (SW^{SF}).

The following lemma can be stated by analyzing Figure 2:

Lemma 1. *The socially optimal type of competition is:*
(i) Facilities-based competition over fiber access networks when $k \in [1.6991, 1.7004]$*;*
(ii) Service-based competition over copper access networks when $k \in [1.7004, 1.8148]$*;*
(iii) Service-based competition over fiber access networks when $k \in [1.8148, 1.8926]$*;*
(iv) Facilities-based competition over fiber access networks when $k \in [1.8926, +\infty]$.

Lemma 1 shows that the type of competition which leads to the highest social welfare depends on the particular level of the fiber investment cost parameter k. Access price regulation is needed when k is relatively low. In this case, social welfare is maximized by service-based competition over either copper or fiber access networks. Hence, the regulator can induce the entrant to undertake its optimal "make-or-buy" decision that leads to the socially optimal competition type by suitably setting the access prices to the copper and fiber access networks. In particular, the regulator sets the welfare-maximizing access price to the network over which service-based competition leads to the highest welfare outcomes subject to the condition that this access price makes the entrant choose the socially optimal competition type. This means that the access price to the other network is set at a level that makes the entrant worse off by seeking access to that network (for instance an infinite access price). Furthermore, if the welfare-maximizing access price distorts the entrant's decision, the regulator sets the closest possible one that makes the entrant choose the socially optimal competition type.

If, on the contrary, the particular value of k is extremely low or relatively high, the society is better off by facilities-based competition. In this case, the regulator sets high access prices for both copper and fiber unbundling in order to induce the entrant to invest in its own fiber access infrastructures. However, it is likely that the incumbent may offer access to one of its networks at its privately-optimal access price and that such price may lead the entrant to be a service-based competitor rather than a facilities-based one.

Recall that under *SF*, the incumbent's profit is $\pi_1^{SF} = \frac{-5(2k-1)a_f^2+10ka_f+2k}{2(9k-2)}$. Taking the first-order condition of π_1^{SF} with respect to a_f gives the privately optimal fiber access price, which is $a_f^* = \frac{k}{2k-1}$. Obviously, this access price cannot be set since it is higher than the critical value $\widehat{a_f}$ which makes the entrant indifferent between *SF* and *FF*. Therefore, the highest possible access price that the incumbent can set is $a_f = \widehat{a_f}$. This access price leaves the entrant with positive profit, but the derived profit for the incumbent is higher than its profit under *FF*. This means that service-based competition over the fiber access network prevails.

In addition, the incumbent's profit under SC is $\pi_1^{SC} = \frac{(9-10k)a_c^2+2(5k-4)a_c+2k}{2(9k-8)}$. In this case, the privately optimal copper access price is $a_c^* = \frac{5k-4}{10k-9}$. Note that this access price is higher than the one that makes the entrant exit the market (i.e., $a_c = \frac{3k-4}{6k-5}$). Therefore, the incumbent sets the highest possible level of a_c that makes the entrant choose to seek copper access. This copper access price is $a_c = \widehat{a_c}$. This access price makes the entrant indifferent between SC and FF, whereas the incumbent prefers SC to FF. Therefore, service-based competition over the copper access network prevails.

As a result, the regulator cannot induce facilities-based competition by setting the access prices for copper and fiber unbundling or by deregulating either or both upstream markets. This implies that banning access to the incumbent's upstream facilities is the only way to lead the entrant to invest in fiber access infrastructures.

The following proposition describes the optimal regulatory scheme that should be imposed depending on the particular value of k:

Proposition 1. *In the first stage, the regulator:*

(i) sets $a_c = \widehat{a_c}$ *and* $a_f \geqslant \frac{k}{2k-1}$ *if* $k \in [1.7004, 1.814\,8]$*;*
(ii) sets $a_f = \widehat{a_f}$ *and* $a_c \geqslant \frac{3k-4}{6k-5}$ *if* $k \in [1.814\,8, 1.892\,6]$*;*
(iii) bans access to the incumbent's upstream facilities if $k \in [1.6991, 1.7004]$ *or* $k \in [1.892\,6, +\infty]$*.*

4 Discussion

The previous section showed that the regulator can induce the entrant to undertake the socially optimal "make-or-buy" decision by setting the access scheme described in Proposition 1. The induced competition type is dependent on the particular level of the investment cost parameter k. It is interesting to point out that all competition types may arise in equilibrium. The social optimality of each competition type depends on its impact on total consumer valuation and total investment cost.

Facilities-based competition over fiber access networks duplicates the investment cost, but the investment of each firm has a positive impact on demand. On the contrary, service-based competition over copper access networks saves the duplication of the investment cost since only the incumbent invests, but the total impact of investment on demand is expected to be lower as the entrant provides the lower broadband services, which are less valued by consumers. Last, service-based competition over fiber access networks also saves the duplication of the investment cost and both firms provide the ultra-fast broadband services, which are more valued by consumers. Of course, the relative effectiveness of each competition type to induce higher total consumer valuation and lower total investment cost depends on the equilibrium investment levels derived by each case. Thus, Figure 3 presents the investment levels derived by implementing the socially optimal access scheme of Proposition 1, where the black thick, the black thin, the green and the red lines represent δ_1^{FF}, δ_2^{FF}, δ_1^{SC} and δ_1^{SF}, respectively, as a function of k.

Figure 3 verifies that the incumbent's investment level is decreasing in k, regardless of the competition type. In addition, the incumbent's investment is always higher under *FF* than under *SF*, whereas *SC* leads to an investment level that is between the ones derived by the other competition types. Regarding the entrant's investment under *FF*, it is shown that δ_2^{FF} is initially very low, then increases with an increase in k and afterwards decreases as k further increases. However, δ_2^{FF} is always lower that δ_1^{FF}.

In addition, Figure 3 shows that when k is extremely low, δ_1^{FF} is very high, whereas δ_2^{FF} is very low. This means that the cost of duplicating fiber investment is mitigated and is outweighed by the significant positive impact of the incumbent's investment on demand. However, as k increases, δ_1^{FF} decreases and δ_2^{FF} increases, both at a high rate. On the contrary, the increase in k, decreases δ_1^{SC}, but at a lower rate than the one at which δ_1^{FF} decreases. This results in significant saves in the total investment cost, which more than compensate the fact that *SC* does not benefit the entrant's consumers from the fiber investment.

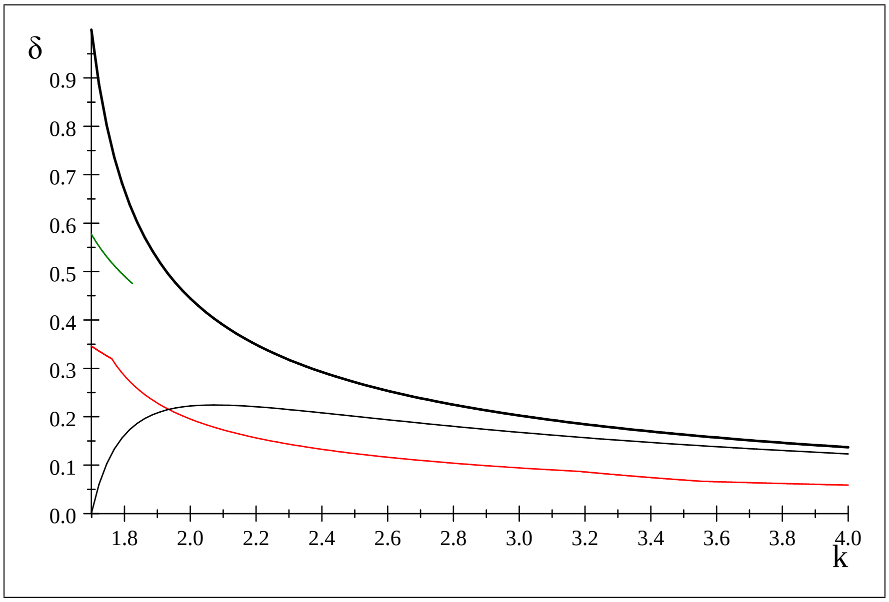

Figure 3: The equilibrium investment levels as a function of k

However, as k further increases, the reduction in δ_1^{SC}, makes SF more attractive to consumers since the derived fiber quality, although lower than δ_1^{SC}, is provided to all consumers. Combining this fact with the lower investment cost of SF than SC explains why $SW^{SF} > SW^{SC}$ for $k \in [1.814\,8, 1.892\,6]$. Note that for $k > 1.\,823\,9$, it is never optimal for the entrant to seek access to the incumbent's copper access networks, and hence, SC cannot constitute an equilibrium.

Moreover, for $k > 1.892\,6$, the socially optimal competition type is facilities-based competition. This result, which is optimal for a very high range of k, is quite striking since the society is better off by the duplication of the fiber access infrastructures when the fiber deployment is costly. First, note that, in this case, the fiber investment levels chosen by the incumbent and the entrant under FF are both higher than the incumbent's respective investment level under FS. Second, the sum of δ_1^{FF} and δ_2^{FF} is always higher than the duplication of δ_1^{SF}, a fact that obviously benefits consumers. Last, the profit of both the incumbent and the entrant increases with an increase in k under FF when k is quite high, whereas their respective profits under FS are decreasing in k. The reason for the positive impact of k on δ_1^{FF} and δ_2^{FF} under FF is that when k is quite high, the entrant's optimal investment level is quite low, and hence, the incumbent cannot significantly influence the entrant's reaction to its investment choice. As a result, both the incumbent and the entrant choose a relatively low investment level which makes each firm's investment cost decrease in k. In other words, the two firms can decrease their investment cost by decreasing the chosen quality, although the investment becomes marginally more expensive. These three facts explain why FF is the socially optimal type of competition when k is at least relatively high.

5 Conclusions

This paper studied the optimal regulatory policy that should be implemented during the transition from copper to fiber access networks when the entrant undertakes a "make-or-buy" decision. The transition phase implies that the entrant can seek access to the incumbent's copper or fiber upstream facilities. Therefore, the option to "buy" also includes another decision concerning the quality of the services that the entrant will provide to its consumers. In addition, in this framework, the option to "make" requires a costly investment in fiber access infrastructures. The entrant's "make-or-buy" decision determines the type of competition established in the market of broadband services. In particular, three different types of competition may arise: service-based competition over copper access networks (SC), service-based competition over fiber access networks (SF) and facilities-based competition over fiber access networks (FF).

It was found that all possible types of competition may prevail in equilibrium. This finding was not so obvious since the authors have verified that service-based competition over copper access networks is never optimal for the entrant when the two firms simultaneously decide on their investment levels or when the entrant's "make-or-buy" decision is made after the fiber deployment by the incumbent.

The regulator can commit to an access scheme, and hence, is able to affect the entrant's "make-or-buy" decision. Therefore, which type of competition will prevail in the market depends on the regulatory policy. It was shown that the socially optimal type of competition depends on the particular value of the investment cost parameter k. If that value is relatively low, then SC is socially optimal for lower values of k in that range, whereas for higher values, SF leads to higher social welfare levels. If, on the contrary, k is extremely low or relatively high, the society is better off by facilities-based competition.

The regulator can induce the entrant to undertake the socially optimal "make-or-buy" decision by setting a suitable access scheme. In particular, whenever service-based competition is socially optimal, the regulator should set the welfare-maximizing access price (or the highest possible one that does not distort the entrant's decision) to the network over which service-based competition leads to higher welfare levels, as well as set the access price to the other network at the level that makes the entrant exit the respective market. On the contrary, whenever facilities-based competition is socially optimal, the regulator may not be able to induce this type of competition by setting the access prices for both access networks or by deregulating the access. In this case, the regulator bans access to the incumbent's upstream facilities in order to induce the entrant to invest in its own fiber access infrastructures. The proposed access scheme, which depends on the particular value of k, ensures that the entrant always undertakes the socially optimal "make-or-buy" decision.

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