Geographically Differentiated NGA Deployment

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Abstract

This paper studies the incentives of an unregulated monopolist to undertake the socially optimal investment in NGA networks when it takes into account the fact that the NGA deployment is a two-dimensional investment decision concerning both the quality (or equivalently, technology) and the geographic coverage. It is found that both the privately and the socially optimal investment decisions result in a geographically differentiated NGA deployment implying that different quality NGA networks are deployed in different geographic areas. In particular, NGA networks of higher (lower) quality are deployed in the more (less) densely populated geographic areas. Although such geographically differentiated NGA investment leads the monopolist to provide a nationwide NGA deployment, it is found that the monopolist underinvests compared to the socially optimal levels of both technology and geographic coverage. In addition, since the objectives of the Europe 2020 Strategy concern both the NGA technology and the NGA coverage, this paper shows that the first objective of providing all Europeans with access to much higher internet speeds of above 30 Mbps is feasible when the demand for NGA-based services is significantly elastic, whereas the second objective of providing internet connection speeds of 100 Mbps to 50% or more of European households is not a feasible goal.

Keywords: Broadband, geographic areas, investment incentives, next generation access networks, telecommunications

1. Introduction

Investments in Next Generation Access (NGA) networks[1], which allow ultra fast internet connections, are expected to have a positive impact on economic growth, employment and social prosperity. This fact has been notably highlighted in the European Commission Recommendation on regulated access to NGA (EC, 2010a) and in the Digital Agenda for Europe (EC, 2010b), whereas it has been empirically proven by Czernich, Falck, Kretschmer and Woessmann (2011) and Katz, Vaterlaus, Zenhäusern and Suter (2010). However, recent data from the European Commission (EC, 2012) shows that European telecommunication operators are reluctant to invest in NGA networks. According to the Dutch regulatory authority, OPTA (2008), the main factors that negatively affect an investor's incentives to invest in NGA networks are: (i) the uncertainty about future demand for new NGA-based services; and (ii) the regulatory uncertainty related to the regulator's limited ability to make *ex ante* credible commitments. Therefore, there is a growing interest among policy makers about the optimal regulatory policy that promotes both competition and investment in NGA networks.

1.1. Regulatory concerns

In fact, the assessment of such optimal regulatory policy is a very complex and challenging task because there are many different factors that affect the profitability of an NGA investment project and the subsequent competition outcomes. This implies that regulators have to make a number of decisions that directly affect the level of NGA deployment and the intensity of competition.

Initially, regulators have to decide the regulatory regime applied to the NGA market. Permanent regulation implies that the *ex ante* imposed remedies hold for the whole lifecycle of the NGA investment, whereas regulatory forbearance refers to the situation where there is no *ex ante* regulation on NGA networks. Regulatory holidays and sunset clauses are intermediate regulatory regimes between regulatory forbearance and permanent regulation. Under regulatory holidays, the investor is not imposed to any regulatory constraints for a predetermined period of time, whereas by imposing a sunset clause, the regulator commits that will withdraw access obligations after a predetermined date. It is obvious that regulatory forbearance or holidays appear superior to the other regulatory regimes in terms of both NGA investment level and the timing of the investments but they fail to promote an efficient competition level (Charalampopoulos, Katsianis and Varoutas, 2011; Gavosto, Ponte and Scaglioni, 2007; Nitsche and Wiethaus, 2011).

Secondly, regulators have to assess the level of the access price that an access seeker should pay to the NGA investor in order to have access to the fibre-based access

[1] According to European Commission (EC, 2010a), Next Generation Access (NGA) networks means wired access networks which consist wholly or in part of optical elements and which are capable of delivering broadband access services with enhanced characteristics (such as higher throughput) as compared to those provided over already existing copper networks. In most cases NGAs are the result of an upgrade of an already existing copper or coaxial access network.

networks. This regulatory decision has attracted much interest in the policy debate. A sizeable number of papers study the effect of different combinations of regulatory regimes and access prices on an operator's investment incentives and on the subsequent social welfare outcomes. A first literature strand concludes that an unbundling policy that boosts entry by alternative operators promotes static efficiency but leads to losses in dynamic efficiency (Bouckaert, van Dijk and Verboven, 2010).[2] This implies that cost-oriented access prices is an effective regulatory tool for fostering service-based competition in order to improve static efficiency, but they cannot promote investments in new NGA networks by either incumbents or entrants since the investors are not compensated for the uncertainty of NGA investment.[3]

As a result, a second literature strand studies the impact of alternative regulatory settings on promoting both static and dynamic efficiency. In particular, this set of papers explores the effectiveness of several investment-contingent access prices to increase both static and dynamic efficiency when a single operator invests under either demand uncertainty (Bender, 2011; Nitsche and Wiethaus, 2011) or regulatory uncertainty (Klumpp and Su, 2010; Sarmento and Brandao, 2007; Tselekounis and Varoutas, 2013), as well as, when two operators invest in non-overlapping areas (Henriques, 2011; Sauer, 2011). This literature concludes that compensating the investor(s) for the uncertainty of NGA investment through an investment-contingent access price can achieve both static and dynamic efficiency under certain demand, cost and regulatory conditions.

The aforementioned papers that study the impact of alternative regulatory regimes and access pricing rules on investment and competition outcomes neglect the fact that there is a period during which both copper and NGA networks are in operation and are competing for customers. Therefore, the third regulatory decision concerns the level of the access price applied to the copper access network. This regulatory task gives rise to a more recent stream of papers which discuss the impact of the regulation of the copper access network on the firms' investment incentives when the NGA market is left unregulated or when there is an interplay between the access prices of the two networks (Bourreau, Cambini and Doğan, 2013; Bourreau, Cambini and Doğan, 2012; Bourreau, Lupi and Manenti, 2013; Brito, Pereira and Vareda, 2012; Cambini and Silvestri, 2012; Cave, Fournier and Shutova, 2012; Inderst and Peitz, 2012; Neumann and Vogelsang, 2013). The main conclusion of this literature is that although a higher access charge for the copper access network seems to lead to lower incentives to invest for the firm owning the copper access network and to stronger incentives to invest for its competitor, a positive

[2] Static efficiency concerns the short-run regulatory goal to provide firms with significant incentives to invest in innovative, differentiated services. Such service-based competition leads to a self-sustaining pro-competitive market structure in which firms behave in a competitive manner, and hence, the consumers enjoy the welfare gains from static efficiency (lower prices, better quality and extended variety of services). On the other hand, dynamic efficiency concerns the long-run goal of access regulation to induce the firms to undertake the socially optimal (efficient) investment decisions in new competing infrastructures. Such facilities-based competition achieves the full benefits of competition, and hence, the consumers enjoy the full welfare gains from dynamic efficiency (maximum market growth in terms of both volume and value so that markets achieve minimized costs, innovative technologies and advanced services).

[3] See Cambini and Jiang (2009) for an excellent review of the theoretical and empirical literature on the relationship between broadband investment and regulation.

correlation between the access prices of the two networks incentivizes the migration to the NGA network.

A last regulatory decision, which has mostly been overlooked in the related literature, concerns the possibility of defining different geographical markets according to the prevailing competitive and cost conditions, and therefore, the imposition of geographically differentiated remedies. Indeed, after a period of obligation of non-discrimination (EC, 2002), currently, price discrimination is allowed to a certain (at least wholesale) extent related to NGA networks in Europe in order to foster innovation and welfare growth by promoting investments (EC, 2010a). Bourreau, Cambini and Hoerning (2013) assume that differentiated wholesale access schemes vary according to the degree of infrastructure competition and point out that the regulator faces a dilemma between setting a lower access charge to maximize per-area welfare by maintaining lower retail prices, and setting a high access charge to maximize investment incentives. They show that differentiated remedies (where access is regulated in non-competitive areas, while access is privately negotiated in competitive areas) can be either too high or too low from a social perspective.

From the above analysis, it can be deduced that the derivation of an optimal regulatory policy that promotes both NGA investment and competition is a very difficult and complex task since it requires the estimation of the impact of four interrelated decisions on the twofold regulatory goal. This task becomes even more complex if we take into account the previously overlooked fact that the deployment of an NGA network is a two-dimensional investment decision.

1.2. The two dimensions of an NGA investment decision

A potential investor in an NGA network has to decide: (i) the quality of the NGA network which is closely related to the provided NGA technology, and hence, to the provided internet connection speeds; and (ii) the geographic coverage of the NGA deployment.

The first decision is related to the part of the copper wire being replaced by fibre optics. There are certain NGA architectures, the most common of which are: (i) Fibre-to-the-Curb (FTTC); (ii) Fibre-to-the-Building (FTTB); and (iii) Fiber-to-the-Home (FTTH). It is obvious that the higher the part of the copper wire being replaced by fibre optics, the higher the internet connection speeds that can be provided to end-users. However, the quality of the NGA network is not only affected by the particular point of the local loop at which the fibre is terminated, but also by the particular access technology used to implement each architecture. In particular, the FFTH architecture can be implement by using either the point-to-point (P2P) connectivity technology, in which each device at the subscriber premises is connected through a dedicated optical fibre to a switch port located at the central office of the investor, or the point-to-multi-point (P2M)/ passive optical network (PON) connectivity technology which divides an optical signal into several shared connections. As a result, an investor in NGA network has to decide the combination of the NGA architecture and the connectivity technology that leads to a deployment of an NGA network of a particular quality (or NGA technology). This decision is closely related to the internet connection speeds that will be provided by the investor to its consumers. The second decision concerns the geographical extent of the NGA deployment. Therefore, the investor also chooses the geographic areas in which a fibre-based access network will be deployed. This decision determines the geographic NGA coverage.

Although the research papers that study the impact of the four interrelated regulatory decisions on investment incentives and competition outcomes separately treat the two dimensions of an NGA investment decision, it should be noted that the investor's decisions concerning the NGA technology and the geographic NGA coverage are closely related. In particular, existing studies assume that a prospective investor in NGA networks chooses either the quality or the geographic coverage of the NGA network. This implies that the investor decides: (i) the quality of the NGA network that will be provided in an exogenously given number of geographic areas; or (ii) the number of geographic areas in which an exogenously given NGA technology network will be deployed. In each case, the investor focuses on one of the two dimensions of the NGA investment decision by taking the other dimension as given. A reasonable extension would be to consider a static modeling approach in which an investor endogenously chooses its optimal NGA technology network that will be deployed only in the geographic areas that the investment is proven to be profitable.

This paper goes one step beyond and models the fact that the investor chooses the NGA technology that will be provided in each geographic area.[4] Therefore, not only the quality of the NGA network and the coverage of the NGA deployment are both endogenously chosen by the investor, but also different NGA technologies may co-exist according to the prevailing demand and cost conditions in each geographic area. This modeling setup is the first step towards studying an operator's incentives to deploy a geographically differentiated NGA network. As a result, this paper derives the provided NGA technology in each geographic area, as well as, the optimal number of areas that will be upgraded to any NGA technology. In addition, it compares the privately optimal two-dimensional investment decision with the socially optimal geographically differentiated NGA deployment. In other words, the aim of this paper is to assess whether the regulatory decision to allow an investor to deploy a quality-differentiated NGA network can promote both static and dynamic efficiency (i.e. induces the socially optimal investment outcome).

It should be noted that the derived results are comparable to the objectives of the Europe 2020 Strategy (EC, 2010b) which envisions that, by 2020, (i) all Europeans will have access to much higher internet speeds of above 30 Mbps and (ii) 50% or more of European households will subscribe to internet connections above 100 Mbps. It is obvious that these goals concern both the NGA technology and the NGA coverage, and hence, the research focus should shift towards modeling approaches that take into account the fact that the NGA deployment is a two-dimensional investment decision which results in a geographically differentiated NGA deployment.

[4] In fact, the investor has also to decide the time at which it will build an NGA network of a particular quality in each geographic area. However, the optimal timing of an NGA investment is studied using dynamic modeling approaches, and hence, is out of the scope of this paper, although we acknowledge that it provides an excellent field for future research.

The remainder of the paper is structured as follows. Section 2 gives an outline of the basic assumptions and definitions of the model. Section 3 compares the privately and the socially optimal investment levels in terms of both quality and geographic coverage in order to assess whether the investor undertakes the socially optimal investment decision. The last section summarizes the main results of this article and proposes the directions for future work.

2. The model

This section presents an innovative modeling setup which aims at reflecting the fact that the NGA deployment is a two-dimensional investment decision which concerns both the NGA technology and the geographic NGA coverage. Since the goal of the paper is to assess whether the regulatory decision to allow an investor to deploy a different quality NGA network in each geographic area can promote both investment and social welfare, all the other regulatory decisions are exogenously chosen in order to simplify the model as much as possible. In particular, it is assumed that the investor is not obliged to provide access to its improved access infrastructures to its competitors, which implies that the monopolist firm invests in NGA networks under regulatory forbearance. Although such monopolistic regime does not resolve the trade-off between static and dynamic efficiency, the study of the derived investment outcomes is very useful for comparison purposes since they obviously represent the upper limit of the investment level. It is further assumed that the deployment of an NGA network eliminates the services provided over the pure copper access network (e.g. ADSL), and hence, the impact of the access price applied to the copper access network is of no significance. The last assumption made concerns the imposition of geographically differentiated remedies. In particular, the monopolist investor is allowed to geographically price discriminate in the retail market, which of course, increases its investment incentives compared to the uniform pricing regime (Alexandrov and Deb, 2012; Tselekounis, Maniadakis and Varoutas, 2013; Valletti, 2006).

The model used in this paper is based on a hypothetical country consisting of a continuum of geographic areas which can be indexed in a decreasing order according to their population density. In particular, geographic areas are indexed by i with $i \in [1, n]$, where low values of i imply geographic areas with high population density, whereas geographic areas that are indexed by i close to n represent rural areas (i.e. with low population density). A monopolist provides a basic "universal-level" broadband service (e.g. ADSL) to all geographic areas at a uniform price. Now assume that the monopolist invests in access network upgrade by deciding which geographic areas will be passed by any technology NGA network and which NGA quality will be provided in each geographic area. Therefore, the monopolist initially determines the geographic extent of the NGA deployment denoted by $x_{\max} \in [1, n]$ and then decides which NGA technology denoted by $y_i \in [y_i^{\min}, y_i^{\max}]$ will be provided in each geographic area x_i, $i \in [1, n]$. Obviously both investment decisions are continuous in $[1, n]$ and $[y_i^{\min}, y_i^{\max}]$, respectively. It is expected that the most densely populated geographic area (x_1) will be covered by the highest quality NGA network ($y_i^{\max}$), whereas the least densely populated, but NGA-passed, area ($x_{\max}$) will be covered by the lowest quality NGA network ($y_i^{\min}$).

Contrary to the existing studies which assume that a higher level of NGA investment in terms of either technology or coverage leads to a more outward parallel shift in the demand curve (and thus equally benefits all consumers), this paper models the fact that a higher NGA technology network positively affects the consumers' willingness to pay for ultra-fast NGA-based services, but its impact declines as it is provided to more rural areas. The reason is that consumers who place a higher (lower) valuation to broadband subscription tend to live in higher (lower) densely populated areas (EC, 2010b; Götz, 2013; Preston, Cawley and Metykova, 2007). In addition, the investment cost is assumed to be increasing and convex reflecting the fact that the NGA investment becomes marginally more expensive as a better quality NGA network is deployed in order to provide end-users with higher internet connection speeds. However, contrary to existing studies which assume an exogenously given slope of the marginal investment cost function, this paper models the fact that the investment cost of providing a particular NGA technology becomes marginally more expensive as it is extended to less densely populated areas. Once again, population density has been proven to be an effective proxy for reflecting the fact that the investment cost per potential user decreases in the population density (Götz, 2013). It is thus obvious that geographic areas not only differ with respect to the cost of rolling out an NGA network of a particular technology, but also with respect to the impact of such NGA deployment on consumers' willingness to pay. Therefore, the demand and the investment cost functions in each geographic area i are given, respectively, by:

$$p_i = A + \frac{y_i}{x_i^2} - \beta q_i \tag{1}$$

and

$$C(i) = \frac{x_i y_i^2}{2} \tag{2}$$

where p_i and q_i denote the retail market price and the quantity supplied, respectively, in each geographic area, $\beta > 0$ represents the slope of the inverse demand function and A represents the maximum valuation that the consumers place to the services provided over the pure copper access network when the NGA investment has not taken place. In addition, x_i reflects the geographic NGA deployment and y_i reflects the NGA technology. A larger x_i implies an NGA deployment to less densely populated areas, whereas a larger y_i implies a fibre deployment closer to the consumers' premises combined with a better connectivity technology. It is obvious that a higher NGA technology positively affects the consumers' willingness to pay, but its impact declines as it is provided to more rural areas. In addition, the investment cost of providing a higher NGA technology becomes marginally more expensive as it is extended to less densely populated areas.

3. Investment and welfare outcomes

This section studies the incentives of an unregulated monopolist to undertake the socially optimal investment decision in terms of both NGA technology provided in each geographic area and geographic coverage of the NGA deployment. As usual, the game is solved backwards. This implies that in the third stage, the investment cost is sunk and the monopolist sets the geographic differentiated retail prices of the different ultra-fast broadband services provided in each area given the level of NGA deployment chosen in the first stage and the quality of the NGA network chosen in the second stage.

3.1. Privately optimal level of NGA technology

The profit function of the investor (net of investment cost) derived from the investment y_i in each geographic region x_i is given by:

$$\Pi_i = p_i q_i \tag{3}$$

Substituting the solution of Eq. (1) with respect to q_i in Eq. (3) and taking the first order condition with respect to p_i gives the retail market price that maximizes the monopolist's profits in each geographic area.

$$p_i^* = \frac{Ax_i^2 + y_i}{2x_i^2} \tag{4}$$

As a result, the optimum quantity supplied in each geographic area is given by:

$$q_i^* = \frac{Ax_i^2 + y_i}{\beta\left(2x_i^2\right)} \tag{5}$$

Obviously, both the retail price and the quantity supplied in each geographic area are positively affected by a higher NGA technology and a higher population density. Substituting Eqs. (4) and (5) into Eq. (3) and taking into account the investment cost in each geographic area given by Eq. (2) yields the profits of the investor in each geographic area as a function of the NGA technology (y_i) and the index of the corresponding geographic area (x_i).

$$\Pi_i = \frac{1}{\beta}\left(\frac{Ax_i^2 + y_i}{2x_i^2}\right)^2 - \frac{x_i y_i^2}{2} \tag{6}$$

Taking the first order condition of Eq. (6) with respect to y_i gives the quality of the NGA network that maximizes the monopolist's regional profits.

$$y_i^M = \frac{Ax_i^2}{2\beta x_i^5 - 1} \tag{7}$$

Equation (7) shows the level of NGA technology y_i that the monopolist investor is willing to install in each geographic area x_i. Obviously, the privately optimal level of the

NGA technology is different among the various geographic areas. In particular, by studying the first and second derivatives of Eq. (7) with respect to x_i, it is concluded that the privately optimal level of NGA technology in each geographic area is a decreasing and convex function of x_i. This implies that the unregulated monopolist chooses a geographically differentiated NGA network in terms of the provided quality. In other words, the less (more) densely populated a geographic area is, the less (more) the extent of NGA upgrade that maximizes the investor's regional profits.

3.2. Socially optimal level of NGA technology

Social welfare is the unweighted sum of profits and consumer surplus. Given that the consumer surplus in each geographic area is given by $CS_i = (q_i^2)/2$, it is deduced that the socially optimal level of NGA technology should maximize the following social welfare function:

$$SW_i = \frac{1}{\beta}\left(\frac{Ax_i^2 + y_i}{2x_i^2}\right)^2 - \frac{x_i y_i^2}{2} + \left(\frac{Ax_i^2 + y_i}{\beta(2x_i^2)}\right)^2 / 2 \tag{8}$$

Therefore, the socially optimal level of NGA technology is given by taking the first order condition of Eq. (8) with respect to y_i:

$$y_i^{SW} = \frac{A(2\beta+1)x_i^2}{4\beta^2 x_i^5 - 2\beta - 1} \tag{9}$$

By studying the first and second derivatives of Eq. (9) with respect to x_i, it is deduced that the socially optimal level of NGA technology in each geographic area is also a decreasing and convex function of x_i. This implies that the society is better off by a geographically differentiated NGA network in terms of the provided quality.

3.3. Comparison of privately and socially optimal levels of NGA technology

The comparison of Eqs. (7) and (9) shows that the level of NGA investment in quality in each geographic area imposed by the investor's private investment incentives is less than the corresponding socially optimal level of NGA investment in quality (i.e. $y_i^M < y_i^{SW}$).

Proof.

$$y_i^{SW} > y_i^M \Leftrightarrow \frac{A(2B+1)x_i^2}{4B^2x_i^5 - 2B - 1} > \frac{Ax_i^2}{2\beta x_i^5 - 1} \Leftrightarrow$$

$$(2A\beta x_i^2 + Ax_i^2)(2\beta x_i^5 - 1) > Ax_i^2(4\beta^2 x_i^5 - 2\beta - 1) \Leftrightarrow$$

$2A\beta x_i^7 > 0$ which holds since $A, \beta, x_i > 0$ ■

Therefore, the following proposition can be stated:

Proposition 1. *The unregulated investor always underinvests compared to the socially optimal investment level of NGA quality (or technology).*

The above result is graphically presented by Figure 1. The solid line reflects the privately optimal NGA quality provided in each geographic area, whereas the dashed line reflects the corresponding socially optimal level.

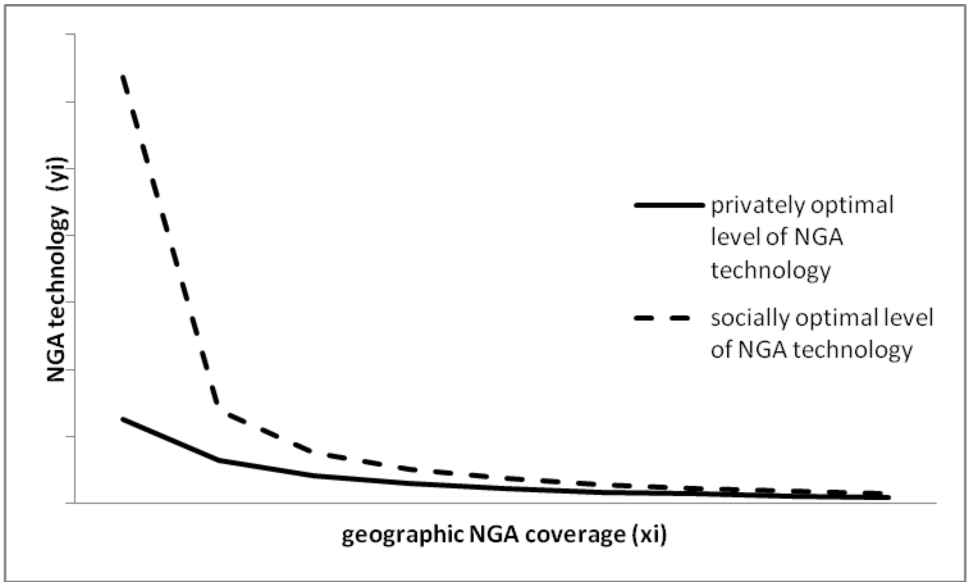

Figure 1. The relationship between x_i and y_i from a private and a social perspective (for $A = 10$ and $\beta = 0.9$)

3.4. Privately and socially optimal levels of geographic NGA coverage

The goal of this section is to derive the privately and the socially optimal levels of geographic NGA coverage. In other words, this section aims at assessing the least densely populated geographic area that will be upgraded to any NGA technology when the investor is the unregulated monopolist and when the NGA investment is undertaken by the society. Substitution Eq. (7) into Eq. (6) gives the regional profits of the investor:

$$\Pi_i = \frac{A^2 x_i^5}{2(2\beta x_i^5 - 1)} \tag{10}$$

It is obvious that the investor's profits in each geographic area are positive. This implies that the unregulated investor is willing to deploy a nationwide quality-differentiated NGA deployment, although the installation of fibre optics in the local loop will be far away from the consumers' premises at the less densely populated areas. This fact gives rise to the following proposition:

Proposition 2. *When the unregulated investor is allowed to deploy a geographically differentiated NGA network, it is willing to invest in all geographic areas within a given country, although the fibre deployment in the less densely populated areas is rather insignificant.*

This result is a very interesting finding since is in contrast with existing studies which conclude that there is an optimal (one-dimensional) investment level that maximizes the investor's profits. Of course, the result of proposition 2 is due to the ability of the investor to maximize its regional profits by providing a different NGA quality network in each geographic area.

However, it is practical to limit our study to the lowest quality NGA network that is technically available. This is the Fibre-to-the-Curb (FTTC) architecture that provides internet connection speeds from 30Mbps to 100Mbps. Obviously, this is the reason that the Digital Agenda for Europe envisions that, by 2020, all Europeans will have access to internet speeds of at least 30Mbps.

Therefore, it is assumed that the highest quality NGA network is achieved by the P2P architecture (which can provide internet connection speeds of up to 1000Mbps) and is denoted by $y_i^{\max}$. It is reasonable to consider $y_i^{\max}$ corresponds to the socially optimal level of NGA technology provided in the most densely populated area. This level is derived by setting $x_i = x_1 = 1$ in Eq. (9). Therefore:

$$y_i^{\max} = y_1^{SW} = \frac{A(2\beta+1)}{4\beta^2 - 2\beta - 1} \tag{11}$$

It is obvious that $y_i^{\max}$ takes its maximum value when the denominator of Eq. (11) is minimized. The positive root of $4\beta^2 - 2\beta - 1$ is $\beta > 0.81$, which implies that $\beta \geq 0.9$ is a sufficient condition to ensure that $y_1^{SW} > 0$. Moreover, given that β negatively affects the optimal level of investment in quality, the highest internet connection speed is achieved for $\beta = 0.9$, and hence, $y_i^{\max*} = y_i^{\max}$ for $\beta = 0.9$, which implies that $y_i^{\max*} \approx 6{,}36A \equiv 1000\text{Mbps}$. Note that in the most densely populated area the privately optimal level of NGA technology is given by setting $x_i = x_1 = 1$ in Eq. (7) and is maximized for $\beta = 0.9$. Hence:

$$y_1^{M} = \frac{A}{2\beta - 1} \tag{12}$$

As a result, the minimum threshold of the internet connection speed that is acceptable in the present study (i.e. 30Mbps) will be provided to the least densely populated area in which an NGA network will be deployed. Let denote this geographic are by $\bar{n} \in [1, n]$. Therefore:

$$y_i^{\min} = y_{\bar{n}} = \frac{30}{1000} y_i^{max*} \Rightarrow y_i^{\min} = \frac{19.08}{100} A \Rightarrow y_i^{\min} = 0.1908A \tag{13}$$

Equating Eqs. (13) and (7) and solving with respect to x_i gives the geographic area in which the monopolist investor will deploy the minimum quality NGA network. In addition, equating Eqs. (13) and (9) and solving with respect to x_i yields the socially optimal geographic area covered by the minimum quality NGA network. The former geographic area reflects the privately optimal geographic NGA coverage $x_{\max}^{M} = \overline{n}$, whereas the latter reflects the socially optimal geographic NGA coverage $x_{\max}^{SW}$. Since both levels of geographic coverage are affected by the slope of the inverse demand function, table 1 provides the impact of β on $x_{\max}^{M}$ and $x_{\max}^{SW}$ for different values of $\beta \in [0.9, 1.9]$.

Table 1 (for $A = 10$ and $y_i^{\min} \approx 1{,}908\text{A}$)

β	$x_{\max}^{M}$	$x_{\max}^{SW}$
0.9	1.4686	1.6903
1.0	1.4206	1.6155
1.1	1.3786	1.5519
1.2	1.3415	1.4971
1.3	1.3083	1.4491
1.4	1.2784	1.4067
1.5	1.2512	1.3689
1.6	1.2264	1.3349
1.7	1.2264	1.3349
1.8	1.2264	1.3349
1.9	1.2264	1.3349

Table 1 reveals that the unregulated monopolist underinvests compared to the socially optimal geographic NGA coverage (i.e. $x_{\max}^{M} < x_{\max}^{SW}$). This is an expected result since the socially optimal level of NGA technology in each geographic area is always higher than the corresponding privately optimal level, and hence, the same level of NGA technology (which, in this case, corresponds to 30Mbps) is privately provided to a more densely populated area than the corresponding socially optimal geographic area.

Table 1 also provides useful implications about the feasibility of the first goal of the Digital Agenda for Europe concerning the provision of access to much higher internet speeds of above 30 Mbps to all Europeans. Assuming that the EC sets its objectives from a social rather than an industrial perspective, the total number of European households will correspond to a particular value of $x_{\max}^{SW}$, which in turn, corresponds to a particular value of β denoted by $\hat{\beta}$. Therefore, if the demand for ultra-fast broadband services is more inelastic than $\hat{\beta}$ (i.e. $\beta > \hat{\beta}$), then the achievement of the first goal of the Digital Agenda for Europe is not feasible. On the contrary, when $\beta < \hat{\beta}$, the fulfillment of this goal is feasible when the privately optimal NGA coverage is at least equal to the socially optimal NGA coverage derived by $\hat{\beta}$. This means that the slope of the inverse demand function for NGA-based services should be significantly flatter than the respective slope that leads to the provision of 30 Mbps to all European households by the socially optimal investment in geographic coverage. The reason in that as the demand for NGA-based services becomes more elastic, the effectiveness of price discrimination to decrease consumer surplus in favor of the monopolist is limited, and hence, the monopolist has incentives to extend its NGA coverage to more geographic areas.

This paper can also assess the feasibility of the second objective of the Digital Agenda for Europe, which refers to the goal of achieving the provision of internet connection speeds of 100 Mbps to 50% or more of European households. Given that $y_1^{SW} \approx 6.36A$ represents the internet connection speed of 1000Mbps, the respective speed of 100Mbps is given by

$$y_i^{'} = \frac{1}{10} y_{i\max} \Rightarrow y_i^{'} \approx 0.636A \qquad (14)$$

According to Eq. (7), the unregulated monopolist is willing to provide this internet connection speed to a particular geographic area. This area is derived by equating Eqs. (7) and (14) and solving with respect to x_i. Since the derived level of x_i is a function of β, table 2 provides the geographic area in which the installed NGA network will provide internet speeds of 100Mbps ($x_{\max}^{M'}$), as well as, the respective socially optimal geographic NGA coverage.

Table 2 (for $A = 10$)

β	$x_{\max}^{M'}$	$x_{\max}^{SW}$
0.9	1.1004	1.6903
1	1.0695	1.6155
1.1	1.0425	1.5519
1.2	1.0186	1.4971
1.3	0.9972	1.4491
1.4	0.9779	1.4067
1.5	0.9603	1.3689
1.6	0.9442	1.3349
1.7	0.9294	1.3349
1.8	0.9158	1.3349
1.9	0.9031	1.3349

In order to assess whether the derived values of $x_{\max}^{M'}$ represent the 50% of the European households, we should first define the total number of the European households. Once again, we use as a point of reference the critical value $\hat{\beta}$ which corresponds to the provision of 30 Mbps to all European households under the socially optimal investment in coverage as presented by the second column of the above table. It is obvious that regardless of the particular value of $\hat{\beta} \geq 0.9$, even the highest level of $x_{\max}^{M'}$, which is achieved for $\beta = 0.9$) implies the provision of internet connection speeds of 100 Mbps to much less than 50% of European households. The reason is that the ratio of ($x_{\max}^{M'} - 1$) to any value of $(x_{\max}^{SW} - 1)$ is lower than 50%.[5] Therefore, the second objective of the Digital Agenda for Europe is not a feasible goal.

4. Conclusions

The goal of this paper was to study the incentives of an unregulated monopolist to undertake the socially optimal investment in NGA networks when it takes into account the fact that the NGA deployment is a two-dimensional investment decision. In particular, the investor has to decide the quality of the NGA network and the geographic coverage of the NGA network. For this reason, a suitable modeling setup was used in order to reflect the fact that as an investment in quality upgrade extended to less densely populated (i.e. more rural) areas, not only it has a declining positive impact on the consumers' willingness to pay, but also becomes marginally more expensive. This paper highlighted the expected result that the investor is better off by deploying a geographically differentiated NGA network (i.e. by installing a different quality NGA network in each geographic area).

The main result of this paper was that although a geographically differentiated NGA investment provides the unregulated monopolist with incentives to install a nationwide NGA deployment, the monopolist underinvests compared to the socially optimal levels of both quality and geographic coverage. However, the fibre deployment in the less densely populated areas was found to be rather insignificant, and hence, certain assumptions were made in order to make the derived results comparable to the Europe 2020 Strategy which envisions that, by 2020: (i) all Europeans will have access to much higher internet speeds of above 30 Mbps; and (ii) 50% or more of European households will subscribe to internet connections above 100 Mbps. It was shown that the former objective is feasible when the demand for NGA-based services is significantly elastic, whereas the latter is not a feasible goal.

Our framework is suitable to be extended in many different directions. Firstly, the focus of regulators is continuously shifting from the regulation of the retail market to the regulation of the wholesale market, and hence, the introduction of competition between an investor and an access seeker will certainly highlight the role of access regulation in encouraging NGA investments and promoting competition. Secondly, it is reasonable to expect that a geographically differentiated NGA deployment calls for geographically differentiated access remedies. Therefore, the modeling approach of Bourreau, Cambini and Hoernig (2013) which studies the impact of differentiated wholesale access schemes on coverage and welfare should be combined with the modeling setup of this paper in

[5] This result holds under the assumption that the household density in each geographic area follows the same distribution as the population density.

order to conclude about the optimal pricing scheme that leads to the socially optimal geographically differentiated NGA deployment. A last interesting extension concerns the introduction of some dynamics in our setting since the most significant factors that affect the NGA deployment change over time. In this case, particular focus should be given on the impact of regulatory uncertainty on investment incentives. The reason is that variations in the demand and cost conditions may require regulatory remedies that change over time which, in turn, increase the risk of an *ex ante* NGA deployment.

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References

Alexandrov, A., & Deb, J. (2012). Price discrimination and investment incentives. *International Journal of Industrial Organisation*, *30*, 615-623.

Bender, C., (2011). How to provide access to next generation networks? The effect of risk allocation on investment and cooperation incentives. Available at: <http://ideas.repec.org/p/mar/magkse/201149.html>.

Bouckaert, J., van Dijk, T., & Verboven, F. (2010). Access regulation, competition, and broadband penetration: An international study. *Telecommunications Policy*, *34*(11), 661-671.

Bourreau, M., Cambini, C., & Doğan, P. (2013). Access regulation and the transition from copper to fiber networks in telecoms. *EUI Working Paper RSCAS 2013/52*.

Bourreau, M., Cambini, C., & Doğan, P. (2012). Access Pricing, Competition, and Incentives to Migrate from 'Old' to 'New' Technology. *International Journal of Industrial Organization*, *30*(6), 713-723.

Bourreau, M., Cambini, C., & Hoernig, S. (2013). Geographic Access Rules and Investments. *EUI Working Paper RSCAS 2013/28*.

Bourreau, M., Lupi, P., & Manenti, F. (2013). Old Technology Upgrades, Innovation, and Competition in Vertically Differentiated Markets. *"Marco Fanno" working paper N.158*.

Brito, D., Pereira, P., & Vareda, J. (2012). Incentives to invest and to give access to non-regulated new technologies. *Information Economics and Policy*, *24*(3-4), 197–211.

Cambini, C., & Jiang, Y. (2009). Broadband investment and regulation: A literature review. *Telecommunications Policy*, *33*(10-11), 559-574.

Cambini, C., & Silvestri, V. (2012). Technology investment and alternative regulatory regimes with demand uncertainty. *Information Economics and Policy, 24*(3-4), 212–230.

Cave, M., Fournier, A., & Shutova, N. (2012). The Price of Copper and the Transition to Fibre. *Communications & Strategies*, (85), 147–168.

Charalampopoulos, G., Katsianis, D., & Varoutas, D. (2011). The option to expand to a next generation access network infrastructure and the role of regulation in a discrete time setting: A real options approach. *Telecommunications Policy*, *35*(9-10), 895-906.

Czernich, N., Falck, O., Kretschmer, T., & Woessmann, L. (2011). Broadband Infrastructure and Economic Growth. *The Economic Journal*, *121*, 505-532.

EC (European Commission) (2012). *Digital Agenda for Europe Scoreboard 2012*. Available at: <http://ec.europa.eu/digital-agenda/sites/digital-agenda/files/KKAH12001ENN-PDFWEB_1.pdf>.

EC (European Commission) (2010a). European Commission Recommendation on regulated access to Next Generation Access Networks (NGA). Available at: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:251:0035:0048:EN:PDF>.

EC (European Commission) (2010b). A Digital Agenda for Europe. Available at: <http://ec.europa.eu/information_society/digital-agenda/publications/index_en.htm>.

EC (European Commission) (2002). Directive 2002/19/EC of the European Parliament and of the Council of 7 March 2002 on access to, and interconnection of, electronic communications networks and associated facilities (Access Directive).

Gavosto, A., Ponte, G., & Scaglioni, C. (2007). Investment in Next Generation Networks and the Role of Regulation: A Real Options Approach. *ISEG-UTL Economics Working Paper No. 031/2007/DE*.

Götz, G. (2013). Competition, regulation, and broadband access to the internet. Telecommunications Policy. http://dx.doi.org/10.1016/j.telpol.2013.03.001

Henriques, D. (2011). Can Access Price Indexation Promote Efficient Investment in Next Generation Networks? Conference on the Economics of Information and Communication Technologies, Telecom ParisTech, Paris.

Inderst, R., & Peitz, M. (2012). Market Asymmetries and Investments in Next Generation Access Networks. *Review of Network Economics*, *11*(1).

Katz, R., Vaterlaus, S., Zenhäusern, P., & Suter, S. (2010). The impact of broadband on jobs and the German economy. *Intereconomics*, *45*(1), 26-34.

Klumpp, T., & Su, X. (2010). Open access and dynamic efficiency. *American Economic Journal: Microeconomics*, *2*, 64-96.

Neumann, K.-H., & Vogelsang, I. (2013). How to price the unbundled local loop in the transition from copper to fiber access networks? *Telecommunications Policy*. http://dx.doi.org/10.1016/j.telpol.2013.05.011

Nitsche, R., & Wiethaus, L. (2011). Access regulation and investment in next generation networks — A ranking of regulatory regimes. *International Journal of Industrial Organization*, *29*(2), 263-272.

OPTA (2008). Policy rules tariff regulation for unbundled fiber access. The Hague, 19 December 2008. Available at: <http://www.opta.nl/en/news/all-publications/publication/?id=2832>.

Preston, P., Cawley, A., & Metykova, M. (2007). Broadband and rural areas in the EU: From technology to applications and use. *Telecommunications Policy*, *31*(6-7), 389–400.

Sarmento, P., & Brandao, A. (2007). Access pricing: A comparison between full deregulation and two alternative instruments of access price regulation, cost-based and retail-minus. *Telecommunications Policy, 31*(5), 236–250.

Sauer, D. (2011). Access rules and investment incentives. Conference on the Economics of Information and Communication Technologies, Telecom ParisTech, Paris, France.

Tselekounis, M., Maniadakis, D., & Varoutas, D. (2013). NGA investment incentives under geographic price discrimination. 40th Annual Conference of the European Association for Research in Industrial Economics (EARIE), Évora, Portugal.

Tselekounis, M., & Varoutas, D. (2013). Investments in next generation access infrastructures under regulatory uncertainty. *Telecommunications Policy*. http://dx.doi.org/10.1016/j.telpol.2013.06.001

Valletti, T. (2006). Differential pricing, parallel trade, and the incentive to invest. *Journal of International Economics*, *70*, 314-324.