How to provide access to next generation networks? The effect of risk allocation on investment and cooperation incentives

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This paper analyzes the incentives to invest in Next Generation Access Networks (NGA) in a framework with horizontal product differentiation with price competition between an investing and an access seeking firm. Given uncertainty about the success of the NGA, I compare regulatory regimes with symmetric and with asymmetric risk allocation to the firms having the opportunity to cooperate and jointly roll-out the NGA. I find that private incentives to cooperate might coincide with the consumer surplus maximizing outcome. Whether the firms realize this socially desirable outcome depends on the outside option, i.e. the implemented access regime. The optimal regulatory policy is not only subject to the probability that the NGA succeed but depends even more on the degree of product differentiation in the retail market. Therefore, the implementation of different access regimes subject to the degree of product differentiation seems favorable. For heterogeneous retail products, an asymmetric risk allocation not only increases the chances of cooperation but lowers the risk of overinvestment. For homogeneous goods, a symmetric risk allocation is superior as it ensures sufficient investment incentives even if competition is very intensive.

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1 Introduction

Currently, there is a broad discussion about the deployment of fiber-based Next Generation Access Networks (NGA) in the telecommunications markets. Due to the importance of telecommunications infrastructures for economic growth[1], the European Commission set ambitious targets regarding the coverage with "ultra-fast broadband" infrastructures.[2] The roll-out of new access fiber networks and the replacement of (large parts of) the existing copper networks, which represented the core telecommunication infrastructure for decades, change the requirements for regulation. The main objective shifted from the optimization of allocative efficiency by the introduction of service-based competition to more dynamic aspects, i.e. the stimulation of investment incentives, while ensuring an adequate level of competition.[3]

In general, investing firms face two different kinds of risk, market risk and regulatory risk. The market risk describes the uncertainty whether the new infrastructure and emerging services generate sufficient demand and willingness to pay to amortize the investments. Dealing with market risk is a typical task of firms in innovative markets and broadly discussed especially in the R&D literature.[4] The difference in network industries is the existence of regulatory constraints.[5] The regulatory risk describes the risk that sunk investment costs are not considered sufficiently by regulatory authorities.[6] In the context of NGA and the existing market risk, this problem is of great importance. In particular, there is a risk that investment costs are only taken into account if the new infrastructure succeeds, i.e. if there is sufficient demand, and that the investing firm has to bear all costs if the NGA fails. Hence, there is a risk of an asymmetric risk allocation between investing and access seeking firms. In view of these risks and the extensive investment requirements related to the NGA roll-out[7], the opportunities of cooperation and joint investments in the network of firms, which compete in the retail markets, have become a more important topic recently.

The New Regulatory Framework[8] allows the introduction of some regulatory instruments to consider the risk related to investments in new infrastructures and the trade-off between static and dynamic efficiency. In general, the private and social incentives to provide the

[1] Cf. Röller & Waverman (2001), OECD (2008), Fornefeld et al. (2008), or Czernich et al. (2011).

[2] Cf. COM (2010) 245 and IP/10/1142. The objective is to ensure broadband access with 30 MBit/s for all and with 100 MBit/s for at least half of all European households by 2020.

[3] As Laffont & Tirole (2001, p.7) pointed out, there exists a Schumpetrian trade-off between static efficiency, i.e. an intense (service-based) competition with a given infrastructure and encouraging investments ex ante.

[4] Cf. Dixit & Pindyck (1994) for a general discussion of uncertain investments.

[5] Cf. Dobbs (2004) for an analysis of an investment game with demand uncertainty in a regulated market.

[6] Guthrie (2006) provides a comprehensive overview of the effect of different regulation regimes and their impact on investment incentives in network industries with emphasis on regulatory risk.

[7] Cf. Elixmann et al. (2008), Katz et al. (2010). Subject to the used technology, the costs of providing broadband access is estimated between 300 € and 2200 € per household.

[8] Cf. COM (2009) 140.

new infrastructures do not differ fundamentally as firms have incentives to tap into new markets. Hence, an important question is how the regulatory framework might support and foster the private investment incentives such that socially desirable objectives might be achieved with a minimum of regulatory interventions.

In the economic literature as well as in practice, the effects of regulation on investment are heavily disputed.[9] In this paper, I focus on a recent work by Nitsche & Wiethaus (2011) and extend their framework model. Nitsche & Wiethaus (*NW* hereafter) compare different regulatory regimes regarding the effects on investment incentives, the competition intensity and the resulting consumer surplus in a two-stage Cournot model with two firms, a vertically integrated incumbent and an access seeking entrant. Similar to Klumpp & Su (2010), the access price used by *NW* considers total investment costs as well as the firms' usage of the new infrastructure. In the presence of uncertainty regarding the success of the NGA, *NW* compare *long run incremental cost regulation* (*LRIC*), a regime with asymmetric risk allocation in which the entrant only bears part of the investment costs if the NGA is a success, to three alternatives. First, *NW* consider a *full distribution of costs regulation* (*FD*) with symmetric risk allocation in which the entrant bears part of the investment costs even if the NGA fails. Secondly, they consider a *risk sharing regulation* (*RS*) in which both firms jointly deploy and use the new infrastructure without any further access fees. Thirdly, they consider *regulatory holidays* (*RH*), i.e. a regime in which the incumbent has no access obligations for the NGA. *NW*'s results are three-part: First, for a given investment level *risk-sharing* yields the highest competitive intensity, i.e. the highest expected total quantity, and *LRIC* performs better than *full distribution*. Secondly, the investment incentives are highest with *full distribution* and *regulatory holidays* followed by *risk-sharing* and *LRIC*. Thirdly, the consumer surplus is always maximized with the *risk-sharing* regime and *full distribution* always outperforms *LRIC*.

In the following, I adjust *NW*'s model regarding several aspects. As a main difference I assume price competition in the retail market. The intense price competition and the fierce service-based competition in the European broadband markets[10] is a potential obstacle for investments in NGA as new services are rarely available yet and the new access networks compete directly with the old technologies.[11] Moreover, investment in telecommunications infrastructures, such as a fiber or cable network, are typically characterized by lumpy sunk investment costs and the opportunity to serve all consumers connected to the infrastructure

[9]Cf. Cambini & Jiang (2009) for a comprehensive overview of empirical as well as theoretical studies regarding the effects of regulation on investment in broadband markets.

[10]Cf. COM (2009) 390 or OECD (2009).

[11]Cf. Bourreau et al. (2011) for an analysis how access regulation and competition in an old infrastructure negatively affects the incentives to invest in new infrastructures.

in a specific area. Hence, the firms' ex post behavior is driven by these two aspects and competition is more about the utilization of the infrastructure than about a capacity choice.[12]

An additional aspect in my model is the consideration of horizontal product differentiation. Even if firms compete in the same market, retail products are no perfect substitutes by themselves, e.g. due to different preferences of consumers or slightly different services.[13] Furthermore, some of the emerging services are quite heterogeneous but use, at least partially, the same infrastructure. For instance, the provision of smart metering requires access to telecommunications infrastructures. Consequently, one might think about situations in which firms provide heterogeneous service bundles, e.g. one firm provides smart metering and one firm provides IP-TV whereas both offer additionally broadband access to their retail consumers.

Another extension of *NW*'s model is the interpretation of their *risk-sharing* regime. As firms, even from different infrastructure industries such as telecommunications and electricity, jointly roll-out and use (parts of) the infrastructure without any further access fee, I interpret this setup explicitly as *cooperation* between firms. This has two effects on the modeling: First, an important question is whether the firms are willing to cooperate as they cannot be forced to do so by regulatory authorities. Therefore, I add another stage of the game in which the firms decide whether to cooperate or not given the implemented access regime. Note that access to the infrastructure might also be interpreted as access to ducts of other infrastructure providers. Secondly, I consider a positive payment from the entrant to the incumbent in this setup, i.e. the entrant bears a fixed part of the investment costs.

Given these extensions, the results partly differ from *NW*'s findings and give some further insights. In contrast to *NW*, there is no single regime which always yields highest investment as *full distribution* as well as *cooperation* might maximize the investment incentives subject to the degree of product differentiation and the probability of success of the new infrastructure. A supplementary insight is that some access regimes contain a threat of no investment if the degree of product differentiation is low, i.e. if firms provide homogeneous goods, even if the success of the NGA is rather certain. The analysis of the *cooperation* decision reveals that the firms' incentives to cooperate are subject to the participation of the entrant in the investment risk and to the regulatory outside option, i.e. the implemented access regime. Both firms prefer to cooperate especially if the retail products are rather heterogeneous and if the success of the NGA is rather uncertain. Another difference concerns the consumer surplus or total surplus maximizing access regime. In opposite to *NW*, *cooperation* is not always the socially desirable regime. The welfare analysis shows that the optimal regulatory policy is mainly subject to the degree of product differentiation. While the implementation

[12] Cf. Kahn (2006).
[13] See e.g. Laffont et al. (1998).

of *full distribution*, i.e. an access regulation with symmetric risk allocation between the firms, seems favorable if the products are rather homogeneous, *cooperation* seems best if products are rather heterogeneous. Subject to the implemented access regulation, the consumer or total surplus maximizing regime might be achieved by the private incentives to cooperate.

The remainder of the paper is structured as follows. Section 2 provides the setup of the model. In Section 3, I derive the equilibrium conditions by solving the subgames of the model recursively. Section 4 concludes.

2 The model

The market is served by two firms, an incumbent denoted by I and an entrant denoted by E. Both firms compete in the Internet broadband access market using a given technology, e.g. DSL, with horizontally differentiated goods. The incumbent may invest in a Next Generation Access Network (NGA) and the entrant receives (regulated) access to the incumbent's network at an access fee w. The roll-out of the new infrastructure is risky as the demand for new services and therefore the success of the infrastructure is uncertain. With probability β, consumers will ask for new services based on this infrastructure and with probability $1-\beta$ consumers prefer service which could be provided with the old network.

2.1 Demand

The retail demands of the entrant and the incumbent, q_E and q_I, are derived from a representative consumer with the following linear-quadratic utility function:[14]

$$U = (\nu + \psi x)q_I - \frac{q_I^2}{2} + (\nu + \psi x)q_E - \frac{q_E^2}{2} - \sigma q_I q_E. \tag{1}$$

The consumer's reservation utility for broadband access is given by ν. For simplicity, let us assume that the reservation utility is the same for both products. The parameter ψ is an indicator function for the success of the NGA. With probability β, there is a demand for new services and products based on the NGA and ψ equals 1. In this case, the demand increases by the extent of the investment x. If there emerge no new services and consumers keep using the common technology, ψ equals 0 and the consumers do not have an additional utility from the new infrastructure. The probability of such a failure of the new technology is $1-\beta$. The extent of the NGA investment x might be interpreted as different NGA technologies, e.g. fiber-to-the-cabinet (FttC), fiber-to-the-building (FttB), or fiber-to-the-home (FttH),

[14]For a detailed description, see Vives (2001, p.145-147). Note that I abstract from the numeraire good.

which allow for different bandwidths and therefore different service qualities. Horizontal product differentiation is represented by the parameter $\sigma \in [0,1]$, whereas σ equals 1 for homogeneous and 0 for independent goods.

Maximizing the utility subject to the budget constraint yields the demand functions

$$q_I = \frac{\nu - p_I - \sigma(\nu - p_E)}{1-\sigma^2} + \psi\frac{x}{1+\sigma} \tag{2}$$

$$q_E = \frac{\nu - p_E - \sigma(\nu - p_I)}{1-\sigma^2} + \psi\frac{x}{1+\sigma}. \tag{3}$$

The demand of each firm increases with the consumer's willingness to pay for broadband access ν and with price of the competitor and decreases with the firm's own price. Additionally, the firms' demand increases with the degree of product differentiation (i.e. if σ decreases). The motivation of this "love of variety" effect is as follow: suppose that the firms originate from different industries, e.g. a telecommunications provider and a electricity supplier, and offer heterogeneous product bundles. For example one firm provides IP-TV and the other smart metering while both firms provide broadband access as an additional service. Hence, total demand might increase as a higher degree of product differentiation yields a higher willingness to pay of the consumers but does not change total market size. If the investment is a success, i.e. for $\psi = 1$, the demand increases with the extent of the NGA roll-out x weighted with the extent of product differentiation. Reconsidering the example with different NGA technologies, the increasing demand is based on a higher quality of the network and a vertical product differentiation to the old technology. If the NGA is a failure, i.e. $\psi = 0$, the investment in the NGA has no effect on the demand.

Further, let us consider a benchmark case in which the market is deregulated and no access obligation exists. The incumbent as monopoly supplier provides services to the retail consumers. Hence, the demand is independent from the degree of product differentiation, i.e. $\sigma = 0$, and the incumbent's retail demand is given by

$$q_I^{RH} = \nu + \psi x - p_I^{RH}.$$

The incumbent's demand increases in the consumer's willingness to pay ν and the extent of the infrastructure investment x if the new network is a success and decreases in the firm's price p_I^{RH}.

2.2 Access regime

A crucial point regarding the investment incentives is the regulatory framework and existing access obligations. In the following, I use two different regulatory setups introduced by

NW in order to compare the investment incentives as well as the effects of these regimes on competition, i.e. (i) long-run incremental costs regulation and (ii) full distribution of costs regulation. Moreover, I adjust *NW*'s (iii) risk-sharing regulation to a setup with cooperation and consider (iv) an benchmark case with an unregulated monopoly.

By assumption the *long-run incremental costs regulation* (*LRIC*) only takes costs of the currently used network into account. In this setup, this means that the investment costs are only included in the access fee if the NGA succeeds. This regime gives rise to an asymmetric allocation of risk between investing and access seeking firms. If the NGA fails, the NGA does not yield additional value and competitors will not ask for access to the new network. The investing firm bears all investment costs alone. In the case that the NGA becomes a success, the return of the incumbent is limited as the entrant might ask for access. When calculating the access charge, the regulator takes the investment costs but not the investment risk into account and there is an asymmetric allocation of the risk between the firms.

In the *full distribution of costs regulation* (*FD*), the investment costs related to NGA are considered in the calculation of the access charge even if the NGA is no success and a symmetric risk allocation is ensured. The access seeking firm has to bear part of the investment costs even if the NGA fails and the firm does not ask for access to the new infrastructure. This might either be interpreted as a consideration of the investment costs in the access fee for the old infrastructure, e.g. the price for local loop unbundeling, or as consideration of the investment costs in the case of virtual unbundling, i.e. the provision of virtually unbundled wholesale access based on the new technology.

The third regime considered is a *cooperation* (*CO*) between the firms. If the firms decide to jointly invest in the infrastructure, the entrant bears part μ of the investment costs with a fixed payment to the incumbent prior to investment and is allowed to use the infrastructure without any further access payment. I will consider two cases of fixed payments. First, I will follow *NW* and assume $\mu = 0$ in order to compare my finding with their results. Thereafter, I will assume that the firms share the investment costs, i.e. $\mu \in [0, \frac{1}{2}]$. This case could be interpreted as a cooperation in which each firm builds its own local network as a local monopolist and both firms get access to the other firms' infrastructure on a bill-and-keep basis.[15] The investment decision in the cooperation case differs from the two regimes above. With regulated access, the incumbent will only consider its own expected profits in its investment decision. If both firms cooperate, I assume that the investment decision is made such that the joint profits of both firms are maximized given competition in the retail market.

[15] Note that the assumption about bill-and-keep omits the opportunity that both firms charge each other a positive fee to increase their marginal costs in order to charge higher prices and to weaken competition. In the following, we ignore such a setup and possibly negative effects of cooperation on competition are excluded. For a discussion of this issue in R&D literature, see e.g. Katz (1986) or D'Aspremont & Jacquemin (1988) .

The access price is borrowed from Nitsche & Wiethaus (2011, p.3) and reads

$$w^{\ell\varrho} = \alpha^{\ell\varrho} \frac{f(x)}{q_I + q_E} \tag{4}$$

where $\varrho = L, FD, CO$ represents the realized regime, $\alpha^{\varrho} = 0, 1$ is a regulatory parameter defining whether the investment costs are considered in the access fee, $\ell = S, F$ represents whether the NGA is a success or not, $f(x)$ are the investment costs for an deployment x, and q_j are the quantities of the firm $j = I, E$. Similar to Klumpp & Su (2010), this setup endogenizes the investment costs in the access fee. Note that the old network is always subject to access regulation and that the access charge is normalized to zero for the sake of simplicity.[16] An overview of the parameter settings and maximization problems at the investment stage subject to the regulatory regimes is presented in Table 1.

Regime (ϱ)	Access parameters	Fixed investment participation	Maximization problem
LRIC (L)	$\alpha^S = 1$, $\alpha^F = 0$	$\mu = 0$	$\max_{p,x} E(\pi_I)$
Full distribution (FD)	$\alpha^S = 1$, $\alpha^F = 1$	$\mu = 0$	$\max_{p,x} E(\pi_I)$
Cooperation (CO)	$\alpha^S = 0$, $\alpha^F = 0$	$\mu \in [0, {}^1/_2]$	$\max_{p,x} E(\pi_I + \pi_E)$

Table 1: Access regimes and parameter settings

Last, I consider *regulatory holidays* (RH), i.e. a case in which the incumbent faces no access obligation at all. By contrast to NW and similar to the situation in the US broadband markets[17] neither the old nor the new network is regulated. This setup provides a benchmark primarily regarding the investment incentives. For the sake of simplicity, I abstract from the opportunity that the entrant negotiate for access or is able to compete by building its own network.

2.3 Firm's profit maximization

Regulated access and cooperation In the access regimes $\varrho = L, FD, CO$, the vertically integrated incumbent's expected profit reads

$$E(\pi_I^{\varrho}) = \beta((p_I^{S\,\varrho} - c)q_I^S + w^{S\varrho}q_E^S) + (1-\beta)((p_I^{F\,\varrho} - c)q_I^F + w^{F\varrho}q_E^F) - (1-\mu)\frac{\gamma}{2}x^2 \tag{5}$$

and consists of its retail and its wholesale revenues as well as its investment costs. The revenues in the case of success and failure of the NGA are weighted with the probabilities

[16] Based on this simplification, possible effects of the regulation of the old network on the demand for services on the new network are not considered. For such an analysis, see Bourreau et al. (2011).

[17] Cf. FCC (2003), FCC (2005).

$0 < \beta < 1$ and $1 - \beta$. The investment costs $(\gamma x^2)/2$ are assumed as strictly convex function to capture the more than proportionally increasing investment costs for the provision of better NGA technologies or higher coverage.[18] The parameter μ represents the portion of the investment costs covered by a fixed payment by the entrant if both firms cooperate. Note that c represents the marginal costs at the retail level and that the marginal costs of the network are normalized to zero in order to increase the comparability of the results to *NW*'s findings.

The entrant's expected profit is given by

$$E(\pi_E^{\varrho}) = \beta((p_E^{S\,\varrho} - c - w^{S\varrho})q_E^S) + (1-\beta)((p_E^{F\,\varrho} - c - w^{F\varrho})q_E^F) - \mu\frac{\gamma}{2}x^2. \tag{6}$$

For simplicity, let us assume an equally efficient entrant with identical marginal costs c for providing the retail product. If the firms decide to cooperate, the entrant bears the fixed part of the investment costs $(\mu\gamma x^2)/2$ prior to investment. With regulated access, the entrant does not participate in the investment costs, i.e. $\mu = 0$.

Regulatory holidays In the benchmark case without access regulation, the incumbent maximize its expected profits

$$E(\pi_I^{RH}) = \beta\left((p_I^{S\,RH} - c)(\nu + x - p_I^{S\,RH})\right) + (1-\beta)\left((p_I^{F\,RH} - c)(\nu - p_I^{F\,RH})\right) - \frac{\gamma}{2}x^2 \tag{7}$$

which consist of its retail revenues in the success and in the failure case, weighted with the probabilities, and the investment costs. As there is no second firm in the market by assumption, the incumbent does not realize any wholesale revenues and has to bear the whole investment costs.

2.4 Timing of the game

The game consists of four stages and the timing is as follows:

1. *Regulation*
   The regulator sets the access regime.

2. *Firms' Cooperation Decisions*
   Firms decide whether to cooperate or not.

3. *Investment Stage*
   The incumbent chooses its investment level, i.e. the extent of the NGA roll-out.

[18]Cf. Elixmann et al. (2008) find that FTTH requires about 5-times higher investments than FTTC. Alternatively, one might interpret the roll-out of the NGA in a geographical context and interpret the more than proportional cost increase in the context of the NGA roll-out in rural areas.

4. *Pricing Stage*
   Both firms set their prices simultaneously and compete in the market. In the case with regulatory holidays, the incumbent sets its retail price.

In the first stage, the regulator sets a regulatory policy, i.e. $LRIC$ or FD. As the regulator sets the access regime ex ante, no commitment or hold-up problem occurs. Alternatively, the $LRIC$ regime might also be interpreted as a situation in which the regulator is not able to credibly commit to consider the investment costs in the access fee ex post independent from the success of the network. If the incumbent considers this as an unreliable commitment, the outcome would be the same as in the case in which the regulator credibly commits not to consider the investment costs in the failure case.

In the second stage, the firms decide whether to cooperate or not. The firms will only chose this opportunity if the profit of each firm is higher compared to a situation with regulated access. If at least one firm refuses to cooperate, access is provided with the given regulatory access regime. This is a major difference to NW's setup as the cooperation decision is endogenized in this framework and not enforceable by the regulatory authority.

In the third stage, the incumbent maximizes its total expected profits via the extent of the NGA roll-out. Remember that the incumbent will maximize the expected joint profits of the firms if both agree to cooperate given the competition on the downstream market.

In the fourth stage, both firms compete in prices in the retail markets. The motivation for price competition is based on the observation of fierce price competition in most broadband markets due to the ex post incentive to utilize the infrastructure.

3 Equilibria

In the following subsections, I solve the four stages of the game recursively to determine the subgame perfect Nash equilibrium.

3.1 Pricing stage

In the last stage of the game, the firms maximize their profits with respect to the price depending on both the extent and the success of the NGA roll-out and given the regulatory regime. Hence, the firms maximize their profits in the realized state of the world, i.e. either the NGA is a success or not, and the profit maximization problems read as

$$\max_{p_I^{\ell\varrho}} \quad \pi_I^{\ell\varrho} = (p_I^{\ell\varrho} - c)q_I^{\ell} + w^{\ell\varrho}q_E^{\ell} \tag{8}$$

$$\max_{p_E^{\ell\varrho}} \quad \pi_E^{\ell\varrho} = (p_E^{\ell\varrho} - c - w^{\ell\varrho})q_E^{\ell} \tag{9}$$

with $\ell = S, F$ and $\varrho = L, FD, CO$. As the investment costs are already sunk in the pricing stage, they are not considered in the profit maximization problem of the firms in this stage of the game.

Rearranging the incumbent's profit functions and substituting the access fee from Equation (4) reveals immediately that both firms face the same opportunity costs of using the NGA:

$$\begin{aligned}
\pi_I^{\ell\varrho} =& (p_I^{\ell\varrho} - c)q_I^\ell + w^{\ell\varrho} q_E^\ell = (p_I^{\ell\varrho} - c - w^{\ell\varrho})q_I^\ell + w^{\ell\varrho}(q_E^\ell + q_I^\ell) \\
=& (p_I^{\ell\varrho} - c - w^{\ell\varrho})q_I^\ell + \alpha \frac{\gamma}{2} x^2 \\
\pi_E^{\ell\varrho} =& (p_E^{\ell\varrho} - c - w^{\ell\varrho})q_E^\ell.
\end{aligned}$$

Both profit functions are symmetric beside the investment costs $f(x) = (\gamma x^2)/2$. This symmetry between both firms is based on the modeling of the access fee and in line with *NW* and with Klumpp & Su (2010)'s revenue neutral access fee formulation.

Regulated access and cooperation In the regimes *LRIC*, *FD*, and *CO*, we substitute the access fee $w^{\ell\varrho}$ according to equation (4) into the profit functions (8) and (9) and differentiating with respect to the prices yield the first order conditions

$$\begin{aligned}
\frac{\partial \pi_i^{\ell\varrho}}{\partial p_i^{\ell\varrho}} =& \frac{\nu + c - 2p_i^{\ell\varrho} - \sigma(\nu - p_j^{\ell\varrho})}{(1-\sigma)^2} + \psi \frac{x}{1+\sigma} \\
&+ \alpha^\ell \frac{\gamma x^2}{2} \frac{(1+\sigma)(\nu + \psi x - p_j^{\ell\varrho})}{(1-\sigma)(2(\nu+\psi x) - p_i^{\ell\varrho} - p_j^{\ell\varrho})^2} \stackrel{!}{=} 0
\end{aligned} \tag{10}$$

with $i, j = I, E$ and $i \neq j$. Note that the firms have symmetric first order conditions as both face the same opportunity costs of using the NGA.

Solving the first order conditions with respect to the prices yield the equilibrium prices

$$p_i^{\ell\varrho *} = \frac{(c + (3-2\sigma)(\nu+\psi x)) - \sqrt{(\nu + \psi x - c)^2 - \frac{1}{2}\alpha^{\ell\varrho}\gamma x^2 (2-\sigma)(1+\sigma)^2}}{2(2-\sigma)} \tag{11}$$

where $\psi = 1$ if the NGA succeeds and $\psi = 0$ if the NGA fails. The value of the access parameter $\alpha^{\ell\varrho}$ in the different regimes are as presented in Table 1. Note that the equilibrium prices exist even if the NGA fails, i.e. $\psi = 0$ and the entrant has to bear a part of the investment costs, i.e. $\alpha^F = 1$, as long as $(\gamma x^2)/2 \leq (\nu - c)^2/4$. This condition states that the total investment costs has to be less or equal to the monopoly profit if the NGA fails and is therefore always satisfied by assumption.[19] The equilibrium prices of both firms

[19] A monopoly supplier would invest as long as its profits are non-negative, i.e. as long as $(\nu - c)^2/4 \geq f(x)$.

increase with the extent of the NGA roll-out x as long as either $\alpha^{\ell\varrho}$ or ψ equal 1. If the NGA is a success, i.e. for $\psi = 1$, the reservation utility of the consumers increases and the firms increase their prices accordingly. In the full distribution regime, prices increase with the extent of investment even if the NGA fails, i.e. for $\psi = 0$. In this case, the investment costs are passed to both firms via the access fee, i.e. $\alpha^{F\,FD} = 1$, and the firms adjust their prices to their increasing marginal (access) costs.

Due to the symmetry of the first-order conditions, both firms charge identical prices in equilibrium. Hence, we get a symmetric equilibrium in which both firms provide the same quantities and charge the same prices. Irrespective of product differentiation, the result of *NW* holds with price competition.[20]

For homogeneous products, i.e. for $\sigma = 1$, prices are equal to the firms' marginal costs:[21]

$$p_i^{\ell\varrho *}|_{\sigma=1} = \frac{1}{2}\left(\nu + \psi x + c - \sqrt{(\nu + \psi x - c)^2 - 2\alpha^{\ell\varrho}\gamma x^2}\right) = c + w^{\ell\varrho *}|_{\sigma=1}.$$

Hence, both firms set their prices according to their marginal costs of providing the retail product c plus the access fee w and the typical Bertrand-outcome for price competition with homogeneous goods applies. For $\sigma < 1$, the equilibrium prices contain a mark-up based on the product differentiation.

Regulatory holidays In the case without any access obligation, the incumbent's profit maximization reads

$$\max_{p_I^{\ell\,RH}} \quad \pi_I^{\ell\,RH} = (p_I^{\ell\,RH} - c)q_I^{RH}.$$

Again, the investment costs are sunk and therefore not considered in this stage of the game. Differentiating the profit function with respect to the price yields the first order condition

$$\frac{\partial \pi_I^{\ell\,RH}}{\partial p_I^{\ell\,RH}} = \nu + \psi x + c - 2p_I^{\ell\,RH} \stackrel{!}{=} 0$$

and solving for the price the equilibrium price

$$p_I^{\ell\,RH*} = \frac{\nu + \psi x + c}{2}. \tag{12}$$

Hence, let us assume that this is indeed the case and the investment costs are sufficiently low that at least one firm might bear them without the risk of negative profits in the failure case.

[20] Note that this symmetry holds not only for two but for n firms as long as the firms face identical costs, identical reservation utilities and the same regulatory regime.

[21] Appendix A.1 provides an analytical proof of this statement.

This monopoly price increases with the willingness to pay ν, with the extent of the infrastructure investment x if the NGA succeeds, and with the marginal costs c.

Comparison of the results In order to compare the different regimes for a given investment level x, let us compare the expected prices

$$E(p_i^{\varrho}) = \beta p_i^{S\varrho *} + (1-\beta) p_i^{F\varrho *} \tag{13}$$

and expected total quantities

$$E(Q^{\varrho}) = \beta(q_I^{S\varrho *} + q_E^{S\varrho *}) + (1-\beta)(q_I^{F\varrho *} + q_E^{F\varrho *}) \tag{14}$$

with $i = I, E$ and $\varrho = L, FD, CO, RH$.

From the equilibrium prices in equation (11), we can immediately capture two aspects. First, the expected prices are always the lowest if the firms cooperate. As $\alpha^{F\,CO} = \alpha^{S\,CO} = 0$, the value of the square root in Equation (11) is always greater than in the other regimes independent from the success of the NGA. Both firms face lower marginal access costs on the downstream market if the NGA succeeds and therefore charge lower prices. Hence, the expected prices are below the expected prices with regulated access. Secondly, the expected prices in the full distribution regime are always greater those in the $LRIC$ regime. If the NGA succeeds, both prices are the same for given investment while prices differ if the NGA fails. With full distribution of costs, $\alpha^{F\,FD}$ equals 1 whereas $\alpha^{F\,L}$ equals 0 with a $LRIC$ regulation. Hence, the price reduction based on the square root is lower with full distribution and therefore expected prices are higher. The intuition is straightforward: In the full distribution regime, both firms face higher marginal access costs on the downstream market if the NGA fails and consequently charge higher prices.

Substituting the equilibrium prices (11) in the demand functions yields the equilibrium quantities in the cases with regulated entry and with cooperation

$$q_i^{\ell\varrho *} = \frac{\nu + \psi x - c + \sqrt{(\nu + \psi x - c)^2 - \frac{1}{2}\alpha^{\ell\varrho}\gamma x^2 (2-\sigma)(1+\sigma)^2}}{2(2-\sigma)(1+\sigma)} \tag{15}$$

with $i = I, E$ and $\varrho = L, FD, CO$. For a given investment level x, the results from above apply analogously. The highest expected total quantity is provided with cooperation and the least expected total quantity is provided in the full distribution regime.

Next, let us consider the case with regulatory holidays. The comparison of the equilibrium price in the RH regime with the price in the CO case reveals that cooperation yields strictly lower expected prices. The results of the comparison of the equilibrium prices in the RH

regime with the access regulation regimes $LRIC$ and FD are ambiguous for a given level of investment. Subject to the success of the NGA and the degree of product differentiation, we can distinguish different outcomes. First, let us consider the case in which the NGA becomes a success and prices in the $LRIC$ and in the FD regime are identical. For a high degree of product differentiation, prices with regulated access might be higher than in the case with the RH regime. This result receives an intuitive explanation if we consider the case with independent goods in which both firms charge the monopoly price, i.e. charge a price equal to their costs plus the monopoly markup. The costs, i.e. the sum of the variable costs and the access price, are higher in the cases with regulated entry as an unregulated monopolist does not face any access fees or opportunity costs of using the network. Consequently, the prices with two firms in the market facing access costs are higher than in the case with only one firm in the market who does not face any access costs. If we look at the other extreme, i.e. at the situation with (nearly) perfect substitutes, prices equal costs and the monopoly price is higher than in the cases with regulated access. Secondly, let us compare the prices in the failure case. The prices in the FD regime might be greater than the price with in the RH regime. This applies if there is a high degree of product differentiation and the same reasoning as in the success case applies. The prices in the $LRIC$ regime are always lower or equal to the monopoly price. This is intuitive if we consider independent products as starting point in which both firms charge the monopoly price, i.e. their costs plus a mark-up. In opposite to the success case, the costs for the investment is not considered in the access fee and the firms face the same costs as an unregulated monopolist. Consequently, prices are the same. As prices decrease with the degree of product homogeneity, it is straightforward that prices with $LRIC$ regulation might not exceed the price in the RH regime.

Proposition 1 summarizes the above findings:

Proposition 1. *For $0 < \beta < 1$, $0 \leq \sigma \leq 1$, $\frac{\gamma}{2}x^2 < \frac{1}{4}(\nu - c)^2$,[22] and a given investment level $x > 0$, it applies*

$$\begin{aligned} (i) \quad & E(p_i^{CO}) < E(p_i^{L}) < E(p_i^{FD}) \\ (ii) \quad & E(Q^{CO}) > E(Q^{L}) > E(Q^{FD}). \end{aligned}$$

[22] As discussed above, $\gamma x^2/2 < (\nu - c)^2/4$ is not a necessary but a a sufficient condition to ensure that the square root is non-negative. Note that the investment costs might be greater if the NGA is a success, i.e. for $\psi = 1$, or if the investment costs are not passed via the access fee in the failure case, i.e. for $\alpha^F = 0$.

Compared to the situation with regulatory holidays, it applies

$$
\begin{aligned}
&(i) \quad E(p_I^{RH}) > E(p_i^{CO}) \\
&(ii) \quad p_I^{S\,RH*} > p_i^{S\,\varrho*} \text{ for } \sigma > \hat{\sigma} \text{ with } \varrho = FD, L \\
&(iii) \quad p_I^{F\,RH*} > p_i^{F\,FD*} \text{ for } \sigma > \breve{\sigma} \text{ and } \; p_I^{F\,RH*} \geq p_i^{F\,L*}.
\end{aligned}
$$

Proof. A formal proof is provided in Appendix A.2. ■

Consequently, for a given level of investment, cooperation yields the lowest prices and highest expected total output. If the regulator implements access regulation, full distribution yields the highest prices and lowest expected output even if the NGA fails. The comparison between regulatory holidays and the regimes with regulated access is ambiguous. *RH* yields higher prices as *FD* and *LRIC* in the success case if the product differentiation of the retail products is not too high. If the NGA fails, the prices with *RH* are always higher compared to the *LRIC* regime but are lower than the prices in the *FD* regime if the products are nearly independent. If we compare our findings to the result of *NW*, it becomes obvious that price competition does not change the competition intensity, as *NW* call it, compared to a setup with Cournot-competition.

3.2 Investment stage

In the investment stage, the incumbent chooses the extent of the NGA deployment. Subject to the firms' decision about a cooperation in the previous stage of the game, the incumbent either maximize its own expected profits or the expected joint profits of both firms.

Regulated Access First, Let us consider the case in which the firms disagree to cooperate. The incumbent maximize its expected profits given the access regime $\varrho = L, FD$ and under consideration of the equilibrium prices and quantitites in the last stage of the game. The incumbent's maximization problem is therefore given by

$$
\begin{aligned}
\max_x \; E(\pi_I^{\varrho}) =& \beta((p_I^{S\varrho*} - c)q_I^{S\varrho*} + w^{S\varrho}q_E^{S\varrho*}) \\
&+ (1-\beta)((p_I^{F\varrho*} - c)q_I^{F\varrho*} + w^{F\varrho}q_E^{F\varrho*}) - \frac{\gamma}{2}x^2. \qquad (16)
\end{aligned}
$$

The incumbent maximizes its expected profit with respect to the investment level x. The first order condition is

$$\begin{aligned}\frac{\partial E(\pi_I^{\varrho})}{\partial x} =& \frac{1}{(2-\sigma)^2(1+\sigma)}\left[\beta(1-\sigma)(\nu+x-c)\left(1+\frac{\nu+x-c}{B^S}\right)\right]\\ &-\gamma x\left[1-\frac{1}{4(2-\sigma)}\left[\beta\alpha^{S\varrho}\left((5-\sigma)-\frac{(\nu+2x-c)(1-\sigma^2)}{B^S}\right)\right.\right.\\ &\left.\left.+(1-\beta)\alpha^{F\varrho}\left((5-\sigma)-\frac{(\nu-c)(1-\sigma^2)}{B^F}\right)\right]\right] \stackrel{!}{=} 0 \end{aligned} \tag{17}$$

$$\text{with} \qquad \begin{aligned} B^S &= \sqrt{(\nu+x-c)^2-\tfrac{1}{2}\alpha^{S\varrho}\gamma x^2(2-\sigma)(1+\sigma)^2}\\ B^F &= \sqrt{(\nu-c)^2-\tfrac{1}{2}\alpha^{F\varrho}\gamma x^2(2-\sigma)(1+\sigma)^2}.\end{aligned}$$

The terms in the first line represent the marginal revenue of the investment in the success case. The terms in the second and third line represent the investment costs for providing the infrastructure lowered by the access payments of the entrant.

The first insight is straightforward: If the success of the NGA is certain, i.e. for $\beta = 1$, the term in the third line disappears and both access regimes have the same first order condition. Consequently, as $\alpha^{S\,FD} = \alpha^{S\,L} = 1$, the optimal investment in both regimes is the same.

As a next step, let us consider the case in which the incumbent does not invest, i.e. $x = 0$. At this point, the derivative of the profit function becomes

$$\left.\frac{\partial E(\pi_I^{\varrho})}{\partial x}\right|_{x=0} = \frac{2\beta(1-\sigma)(\nu-c)}{(2-\sigma)^2(1+\sigma)}.$$

From this equation it becomes obvious that the choice of no investment is only optimal, i.e. only satisfies the first order condition, if either the retail products are perfect substitutes, i.e. if $\sigma = 1$, or if there is no probability of success of the NGA, i.e. if $\beta = 0$. Note that this finding does not necessarily hold inversely. If we assume homogeneous retail products and substitute $\sigma = 1$ in the derivative of the profit function, we obtain

$$\left.\frac{\partial E(\pi_I^{\varrho})}{\partial x}\right|_{\sigma=1} = -\gamma x(1-\beta\alpha^{S\varrho}-(1-\beta)\alpha^{F\varrho}).$$

In the *FD* regime, i.e. for $\alpha^{S\,FD} = \alpha^{F\,FD} = 1$, the first order condition is *always* satisfied and a positive investment level x might also be optimal. Contrary to this, the derivative of the profit function in the *LRIC* regime, i.e. for $\alpha^{S\,L} = 1$ and $\alpha^{F\,L} = 0$, is strictly negative. Consequently, if both firms provide homogeneous retail products, the firm will never invest in the *LRIC* regime. This is a major difference to *NW*'s setup with Cournot-competition as *LRIC* always yields positive investment in their setup if there is a positive probability of success. Given rather homogeneous products and fierce competition on the retail market, the new infrastructure will never be built. Hence, there exists a significant difference between the modeling with Cournot competition and price competition. Additionally, the trade-off between static and dynamic efficiency, i.e. fiercer retail competition with a given infrastructure and incentives to invest in new infrastructures, becomes evident in this case.

Finally, let us compare the investment incentives in both access regimes in general by assuming that in both cases the same investment level x is chosen. Subtracting the derivative of the profit function in the *LRIC* regime from the derivative of the profit function in the *FD* regime yields

$$\frac{\partial E(\pi_I^{FD})}{\partial x} - \frac{\partial E(\pi_I^{L})}{\partial x} = \frac{\gamma x(1-\beta)}{4(2-\sigma)} \left(5 - \sigma - \frac{(\nu - c)(1-\sigma^2)}{\sqrt{(\nu-c)^2 - \frac{1}{2}\gamma x^2 (2-\sigma)(1-\sigma)^2}}\right).$$

If the success of the NGA is uncertain, i.e. for $\beta < 1$, the first term is strictly non-negative. The term in brackets is non-negative for

$$\frac{\gamma}{2}x^2 \leq (\nu - c)^2 \frac{\sigma(\sigma+1)^2 + 12}{(5-\sigma)^2(\sigma+1)^2}.$$

Note that for homogeneous goods, i.e. $\sigma = 1$, the second expression on the right-hand side is minimized and equals $1/4$. Hence, if the investment costs are weakly lower than $(\nu - c)^2/4$, the derivative of the profit function in the *FD* regime is always greater than the derivative of the profit function in the *LRIC* regime. This means that the investment level x which satisfies the first order condition in the *LRIC* regime yields a positive derivative of the profit function in the *FD* regime. Consequently, the investment incentives in the *FD* regime are always greater as profits increase if the firm choses a higher investment level.

Cooperation Let us now consider the case in which both firms decided to cooperate in the second stage of the game. In this case, the incumbent maximizes the joint profits of the firms under consideration of the competitive retail prices and quantities in the subsequent stage of the game. The maximization problem reads

$$\begin{aligned} \max_x \; E(\pi_I^{CO} + \pi_E^{CO}) =& \beta \left((p_I^{S\,CO*} - c) q_I^{S\,CO*} + (p_E^{S\,CO*} - c) q_E^{S\,CO*} \right) \\ &+ (1-\beta) \left((p_I^{F\,CO*} - c) q_I^{F\,CO*} + (p_E^{F\,CO*} - c) q_E^{F\,CO*} \right) - \frac{\gamma}{2} x^2 \qquad (18) \end{aligned}$$

with $\alpha^{S\,CO} = \alpha^{F\,CO} = 0$. The derivative of the joint profit function with respect to the investment level x is

$$\frac{\partial E(\pi_I^{CO} + \pi_E^{CO})}{\partial x} = \beta \frac{4(\nu + x - c)(1-\sigma)}{(2-\sigma)^2(1+\sigma)} - \gamma x \stackrel{!}{=} 0 \tag{19}$$

and solving for the optimal investment yields

$$x^{CO*} = \frac{4\beta(\nu - c)(1-\sigma)}{\gamma(2-\sigma)^2(1+\sigma) - 4\beta(1-\sigma)}. \tag{20}$$

If the firms decide to cooperate, it is only optimal not to invest if the products are perfect substitutes, i.e. for $\sigma = 1$, or if there is no probability of success, i.e. for $\beta = 0$. Otherwise, the incumbent will always invest in the NGA. Note that the incumbent's investment decision is independent from the entrant's participation in the investment costs, i.e. independent from μ.

Regulatory holidays If the incumbent does not face any access obligations, it maximizes its expected profit under consideration of the equilibrium prices in the pricing stage. Therefore, the incumbent's maximization problem is given by

$$\max_x E(\pi_I^{RH}) = \beta \left((p_I^{S\,RH} - c) q_I^{S\,RH} \right) + (1-\beta) \left((p_I^{F\,RH} - c) q_I^{F\,RH}) \right) - \frac{\gamma}{2} x^2.$$

Differentiating with respect to the investment level yields the first order condition

$$\frac{\partial E\left(\pi_I^{RH}\right)}{\partial x} = \beta \frac{\nu + x - c}{2} - \frac{\gamma}{2} x^2 \stackrel{!}{=} 0$$

and is solved for the optimal investment level

$$x^{RH*} = \frac{\beta(\nu - c)}{2\gamma - \beta}. \tag{21}$$

The optimal investment in the RH regime increases with the willingness to pay ν and with the probability of success β whereas it decreases with the investment cost parameter γ and with the marginal costs c. Note that the the incumbent will always invest in this regime as long as there is a positive probability of success, i.e. as long as $\beta > 0$ applies.

Comparison of the results Even though the first order condition (17) does not provide a closed-form solution, the previous discussion allows us to note the following propositions:

Proposition 2. *For homogeneous goods, i.e. for $\sigma = 1$, the incumbent might only invest in the*

NGA if the regulator implements the FD regime or if there are no access obligations. If the regulator implements a LRIC regime or if the firms decide to cooperate, the optimal investment level x equals zero.

Proof. Follows from the discussion above. ■

These findings are a major difference to *NW*'s findings. Given their setup with Cournot-competition, firms are always able to charge a price above costs. Considering the intense service-based competition in telecommunications, the threat of no investment in new infrastructure seems at least somewhat plausible and should be taken into account.

Proposition 3. *For* $0 < \beta < 1$ *and* $0 \leq \sigma \leq 1$, *it applies*

(*i*) $x^{FD*} \geq x^{L*}$

(*ii*) $x^{CO*} > x^{L*}$ *for* $0 \leq \sigma < \tilde{\sigma}(\beta)$ *and* $x^{CO*} \leq x^{L*}$ *for* $\tilde{\sigma}(\beta) \leq \sigma \leq 1$

(*iii*) $x^{CO*} > x^{RH*}$ *for* $0 \leq \sigma < \check{\sigma} \approx 0.61$ *and* $x^{CO*} \leq x^{RH*}$ *for* $\check{\sigma} \approx 0.61 \leq \sigma \leq 1$

Proof. For a proof of the first statement, see the argumentation above. For a proof of the second and the third statement, see Appendix A.3. ■

Simulations of the optimal investment decisions x^{ϱ} give some more detailed insights about the NGA deployment in the different regimes. Figure 1 illustrates the relation between the investment in the three regimes for different ranges of σ and β.

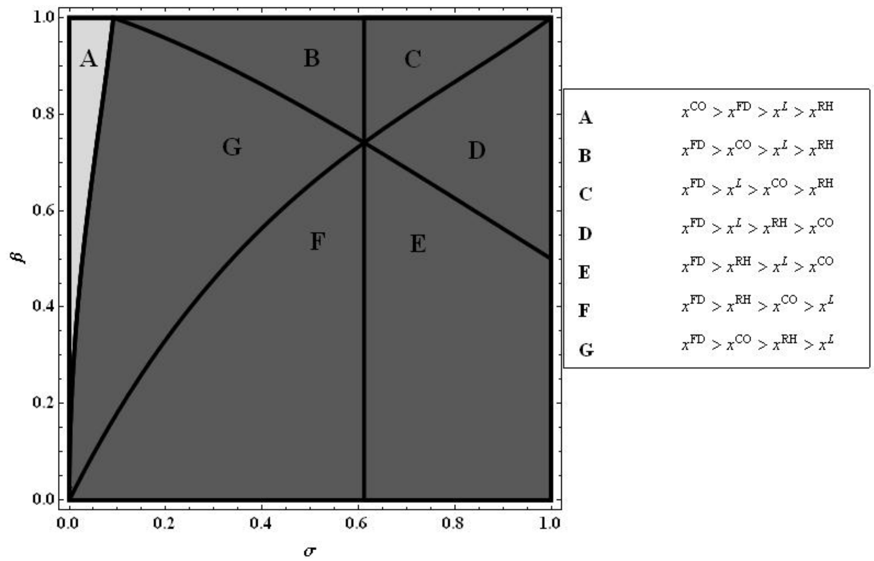


Figure 1: Relative equilibrium investment subject to β and σ
(for $\nu = 100$, $c = 20$, and $\gamma = 5$)

The results from Proposition 3 and the simulation are similar to *NW*'s findings. The higher investment incentives with *FD* compared with *LRIC* are intuitive. The symmetric risk allocation allows the incumbent to invest more as the investment costs will be partially covered by the entrant independent from the NGA's success. Therefore, the incumbent is not put at competitive disadvantage if the NGA fails. A difference to *NW* is that cooperation might yield higher investment than *FD* and *LRIC* subject to product differentiation and risk. Cooperation seems to be favorable with respect to the investment incentives if the products are highly differentiated. If the degree of product differentiation decreases (σ increases), *LRIC* yields higher investment as cooperation if the probability of success is relatively high (regions *C*, *D*, and *E*). The lower the product differentiation (the higher σ), the higher might be the investment risk for which *LRIC* is superior to *CO*. Regulatory holidays yield lower investment as *FD* but might yield higher investment as *LRIC* if either the degree of product differentiation is low (σ is high) or if the probability of success is low (regions *E*, *F*, and *G*). Compared to cooperation, regulatory holidays yields higher investment for closer substitutes independent from the probability of success (regions *D*, *E*, and *F*).

3.3 Firms' cooperation decision

In the second stage of the game, the firms decide whether to cooperate or to use the given access regime. With a given regulatory access regime $\varrho = L, FD$, the profits of the firms are as defined in equations (5) and (6) without a fixed participation of the entrant in the investment costs, i.e. with $\mu = 0$. If the firms decide to cooperate, the entrant bears a fixed part of the investment costs μ. Based on the results in the pricing stage, i.e. a symmetric equilibrium in which both firms provide services for the same retail price and consequently sell the same quantities, let us assume that both firms provide each other access on a bill-and-keep basis.[23] The firms' profits with cooperation then read

$$E(\pi_I^{CO}) = \beta\left((p_I^{S\varrho*} - c)q_I^{S\varrho*}\right) + (1-\beta)\left((p_I^{F\varrho*} - c)q_I^{F\varrho*}\right) - (1-\mu)\frac{\gamma}{2}x^{\varrho 2}$$
$$E(\pi_E^{CO}) = \beta\left((p_E^{S\varrho*} - c)q_E^{S\varrho*}\right) + (1-\beta)\left((p_E^{F\varrho*} - c)q_E^{F\varrho*}\right) - \mu\frac{\gamma}{2}x^{\varrho 2}$$

with the entrant's share of the investment costs $\mu \in [0, 1/2]$.

In the following, I discuss three different cases. First, I analyze the case in which the entrant does not participate in the investment costs, i.e. $\mu = 0$. This case is motivated by *NW*'s setup and allows us to compare this setup with price competition and differentiated retail products to their findings. A major difference to their model is that they interpret this regime as risk-sharing and therefore as a regulatory access regime. In this setup, I assume

[23] As stated in footnote 15, the assumption about bill-and-keep omits the opportunity that both firms charge each other a positive fee in order to increase their marginal costs in order to charge higher retail prices. In this setup, I can show that a positive access fee has always a negative effect on the entrant's profits and that the entrant will only agree to such an access fee if the incumbent makes a side-payment to the entrant.

that firms voluntarily decide whether they want to cooperate and might not be forced to cooperation by the regulator. Secondly, I will consider a setup in which both firms share the investment costs equally, i.e. $\mu = 1/2$. Thirdly, I consider the case that the entrant partially participates in the investment costs, i.e. $0 < \mu < 1/2$.

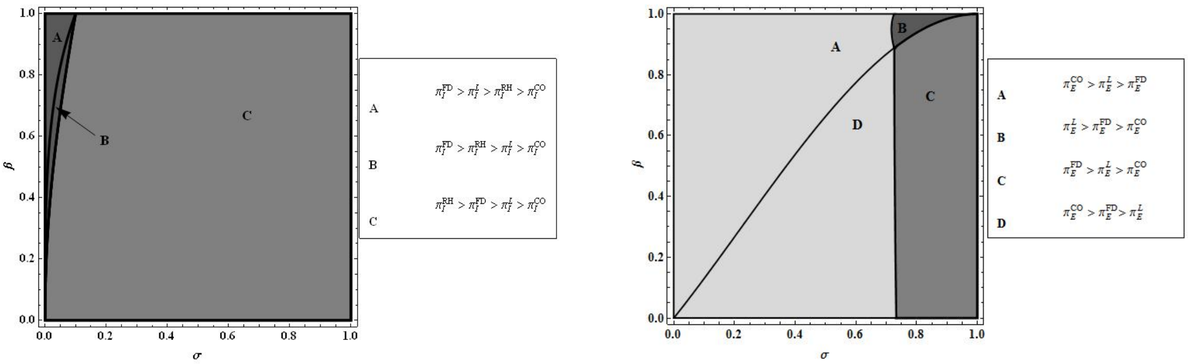
A firm will agree to cooperate if its expected profit is at least as large as its expected profit with regulated access, i.e. if $E(\pi_i^{CO}) \geq E(\pi_i^{\varrho})$ with $\varrho = L, FD, M$ applies. Only if both firms prefer a joint roll-out the cooperation is carried out. If at least one firm disagrees, the regulatory access regime is realized. As there is no closed-form solution of the investment decisions in the *LRIC* and the *FD* regime, I numerically simulate the profits in the different regimes under consideration of the equilibrium prices and equilibrium investment in the third and fourth stage of the game.

No risk participation of the entrant Let us first consider the case without participation of the entrant, i.e. with $\mu = 0$, as a benchmark based on *NW*'s setup.

Figure 2a illustrates the incumbent's profit maximizing regimes subject to the probability of success β and the degree of product differentiation σ. The numerical simulations show that the incumbent will never agree to a cooperation if the entrant does not bear a part of the investment costs. The profit with cooperation is inferior to all other opportunities, i.e. for $0 < \beta < 1$ and $0 \leq \sigma \leq 1$ applies $E(\pi_I^{RH}), E(\pi_I^{FD}), E(\pi_I^{LRIC}) > E(\pi_I^{CO})$. This is straightforward: compared to the cases with regulated access, the incumbent would only provide costless access and waive the wholesale revenues if it agrees to cooperate. Interestingly, the incumbent might prefer regulated access to the monopoly outcome if the products are sufficiently heterogeneous (Region *A* and *B*) as the additional wholesale profits dominate the decreasing profits due to competition.

Figure 2b illustrates the entrant's profit maximizing regimes subject to the probability of success β and the degree of product differentiation σ. The entrant prefers cooperation to regulated access if the products are sufficiently heterogeneous (Region *A* and Region *B*). For homogeneous products, i.e. for high σ, the entrant prefers the regulated access and will refuse to cooperate. If the success of the new infrastructure is nearly certain, the entrant's profits are maximized with *LRIC* regulation as the expected access fee is lower for $\beta < 1$ and the incumbent's investment incentives are already sufficiently high (Region *B*). For some uncertainty about the NGA's success, the entrant realizes higher profits in the *FD* regime (Region *C*). At first view, it might look inconsistent that the entrant prefers regulated access to a regime with costless access but the intuition is straight forward: if the products are very homogeneous, the negative effect of fiercer retail competition on profits is dominated by the higher investment incentives of the incumbent with regulated access. This also explains why the entrant realizes higher profits with the *FD* regime than with the

$LRIC$ regime if the success of the NGA is uncertain. The higher the incumbent's investment incentives due to higher product differentiation, i.e. for a lower σ, the lower the probability of success β for which the entrant is indifferent between the $LRIC$ and FD regime. If the product differentiation is sufficiently high due to the high degree of product differentiation, the additional investment incentives based on the access payments become less important and the entrant would prefer to cooperate.



(a) Incumbent's profits

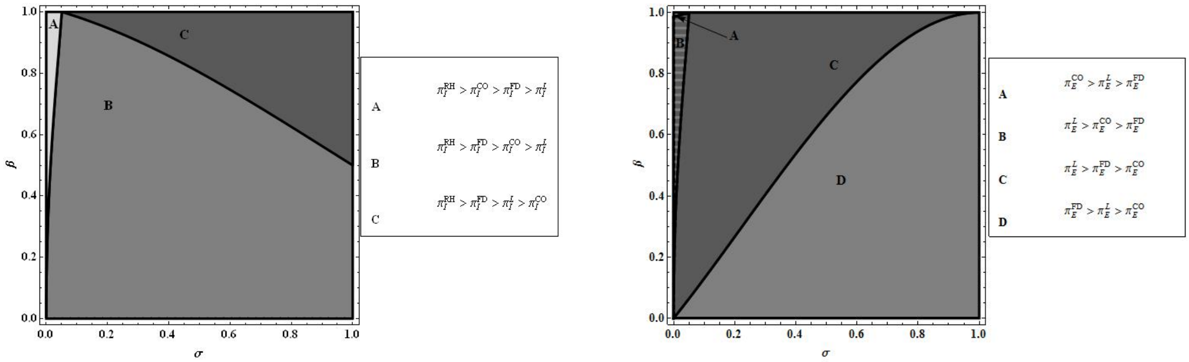
(b) Entrant's profits

Figure 2: Equilibrium profits subject to β and σ (for $\nu = 100$, $c = 20$, $\gamma = 5$, and $\mu = 0$)

Equal risk participation of both firms Let us now consider the case in which the entrant bears half of the investment costs, i.e. $\mu = 1/2$.

Figure 3 illustrates the firms' maximum profits in the different regimes as a function of the probability of success β and the product differentiation parameter σ. The simulation shows that both firms will – independent from the regulatory access regime – only agree to cooperate for a small range of parameter values in which the probability of success is very high and products are nearly independent (region A in Figure 3b). For highly differentiated goods, both firms might also chose to cooperate, even for lower probabilities of success and lower degree of product differentiation, if the regulator implements a FD access regulation (intersection of Region A in Figure 3a and Region A and B in Figure 3b).

An interesting insight from this illustration is that the incentives of both firms might fall apart. The incumbent realizes higher profits with cooperation for almost all parameter combinations if the regulator implements a FD regulation. If the regulator implements a $LRIC$ access regime, the incumbent might prefer a cooperation agreement, especially if the success of the NGA is relatively uncertain (Region B). Hence, in order to increase the incumbent's cooperation incentives, the regulator has to implement a $LRIC$ regulation. In opposite to this, the entrant prefers the $LRIC$ regime to cooperation for almost all parameter values. This becomes clear if we reconsider the above case with $\mu = 0$: due to the high fixed costs, cooperation becomes worse in comparison to regulated access. The profitability of cooperation decreases and – graphically – shifts to the upper left side, i.e. only exists for very heterogeneous goods and a high probability of success.



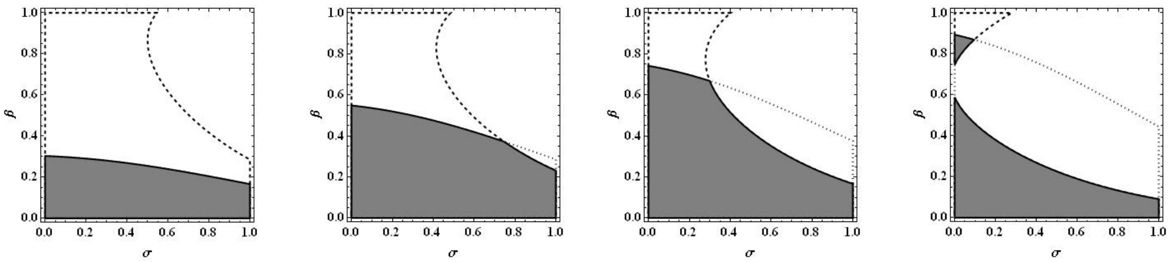
(a) Incumbent's profits (b) Entrant's profits

Figure 3: Equilibrium profits subject to β and σ (for $\nu = 100$, $c = 20$, $\gamma = 5$, and $\mu = 1/2$)

Partial risk participation of the entrant The key problem to get firms into a cooperation agreement are the diverting incentives of both firms. On the one hand, the entrant's profits decrease with the share of investment costs μ and cooperation becomes less attractive in comparison to regulated access. On the other hand, the incumbent strictly prefers regulated access to cooperation if the entrant does not bear a part of the investment costs. In the case with equally shared investment costs, the entrant's incentives for cooperation are too weak and consequently, both firms will only agree to cooperate in very few cases. Above results change if we consider the case in which the entrant bears only some fraction of the investment costs, i.e. $0 < \mu < 1/2$.

Figure 4 illustrates the parameter ranges for which *both* firms prefer cooperation to $LRIC$ for different shares μ. The parameter combinations for which the profits are higher with cooperation than with $LRIC$ are marked by the dotted area for the incumbent and by the dashed area for the entrant. The gray shaded intersection represents the intersection of both areas, i.e. the parameter combinations for which both firms prefer to roll-out the infrastructure jointly instead of using the $LRIC$ access regime and cooperation takes place.

Intuitively, the higher the share of the investment costs covered by the entrant μ, the greater the range of parameters for which the incumbent prefers cooperation and for which the entrant prefers regulated access and vice versa. Thereby, the incumbent's preference for cooperation is less based on the degree of product differentiation but on the probability of success of the NGA. The entrant's decision between the $LRIC$ regime and cooperation is subject to both parameters. The higher the product differentiation, the higher the entrant's willingness to cooperate even in situations with a high probability of success. Below the line, it follows that the decision of the firms is less based on the degree of product differentiation



(a) $\mu = 0.3$ (b) $\mu = 0.35$ (c) $\mu = 0.4$ (d) $\mu = 0.45$

Figure 4: Firms prefer cooperation to LRIC subject to β and σ for different shares μ (for $\nu = 100$, $c = 20$, and $\gamma = 5$)

but on the probability of success.

Above discussion is summarized with the following remark:

Remark 1. *Firms might agree to cooperate if and only if the entrant bears a part of the investment risk, i.e. covers a part of the investment costs. The cooperation decision is then subject to the implemented access regulation $\varrho = L, FD$, the degree of product differentiation σ and the probability that the new infrastructure becomes a success β.*

(i) If the regulator implements the LRIC regime, cooperation will only take place if the investment risk is relatively high. The greater the degree of product differentiation, the greater the range of risk for which both firms agree to roll-out the infrastructure jointly. Thereby, the cooperation decision is crucially subject to the entrant's share of the investment costs μ.

(ii) If the regulator implements the FD regime or no access obligation, firms might only agree to cooperate if the products are nearly independent and the success of the new infrastructure is very high.

To summarize, in NW's setup without a risk participation of the entrant, i.e. for $\mu = 0$, firms will never cooperate as the incumbent always prefer regulated access over cooperation. If both firms bear half of the investment costs, i.e. for $\mu = 1/2$, cooperation will only take place in a small range of parameter values, i.e. for nearly independent goods and a nearly certain success of the new infrastructure. With an implemented FD regulation, the entrant might agree to cooperate if the products are highly differentiated. Otherwise, the entrant will prefer regulated access over cooperation. Given an unequal risk participation of the entrant, i.e. $0 < \mu < 1/2$, both firms might agree to jointly build the infrastructure if the investment risk is sufficiently high and if the regulator implements a $LRIC$ regulation. Hence, the outside option, i.e. the implemented regulatory access regime, plays a crucial role regarding the firms' decision whether to cooperate.

The threat of "late entry" The result that the implementation of the $LRIC$ regime is almost a precondition in order to achieve cooperation agreements raises a potential issue regarding the robustness of the model. While all previous results seem to be qualitatively robust even if more than two firms are in the market, as long as all firms face the same conditions, the decision to jointly build the infrastructure does not necessarily hold for three or more firms. Given a cooperation agreement of two firms and the opportunity of "late entry", additional firms might ask for access and compete in the retail market if the success of the new infrastructure is revealed. Due to the higher investment with cooperation, the equilibrium prices charged by the cooperating firms might be above the access fee and firms without own infrastructures might undercut the cooperating firms' prices. Consequently, such an opportunity would definitely decrease the firms' incentives to cooperate. In principle, there are several approaches to avoid such a distortion of the cooperation incentives. One obvious solution is to release the cooperating firms from any access obligation. In this case, access to late entrants would only be provided if the cooperating firms agree to sell access to their infrastructure. However, it is questionable how such a policy would affect the retail competition as this might raise concerns about foreclosure and collusion. Another possible solution to this issue is currently discussed in France:[24] if a firm decides to invest in a NGA infrastructure, it has to inform its competitors and provide the opportunity of a joint roll-out. Subject to the number of firms which build the infrastructure cooperatively, there is an obligation to provide additional fibers in order to allow firms to enter the market after the infrastructure is in place. Thereby, the access fee for late entrants includes a "risk-premium" which takes the initial investment risk into account.

3.4 Optimal regulatory policy

In the first stage of the game, the regulator has to decide which access regime to implement and whether to allow cooperation between firms.

Consumer surplus maximizing policy As a first step, let us assume that the regulator only takes considers the consumer surplus but not the producer surplus. The consumer surplus as function of the prices given the success of the NGA $\ell = S, F$ is derived from the utility

[24]Cf. Bourreau et al. (2010).

function (1) and reads

$$
\begin{aligned}
CS^{\ell\varrho} =& U - \left(p_I^{\ell\varrho*} q_I^{\ell\varrho*} + p_I^{\ell\varrho*} q_E^{\ell\varrho*}\right) \\
=& \frac{(\nu + \psi x^{\varrho*} - p_I^{\ell\varrho*})^2 + (\nu + \psi x^{\varrho*} - p_E^{\ell\varrho*})^2 - 2\sigma(\nu + \psi x^{\varrho*} - p_I^{\ell\varrho*})(\nu + \psi x^{\varrho*} - p_E^{\ell\varrho*})}{2(1-\sigma^2)}.
\end{aligned}
$$

We derive the expected consumer surplus subject to the investment, the realized regime $\varrho = FD, L, CO$, the degree of product differentiation, and to the success of the NGA by substituting the equilibrium prices from the pricing stage, i.e. Equation (11). Rearranging yields the expected consumer surplus

$$
\begin{aligned}
E\left(CS^{\varrho}\right) =& \beta \frac{\left(\nu + x^{\varrho*} - c + \sqrt{(\nu + x^{\varrho*} - c)^2 - \frac{1}{2}\alpha^{\ell\varrho}\gamma x^{\varrho*\,2}(2-\sigma)(1+\sigma)^2}\right)^2}{4(2-\sigma)^2(1+\sigma)} \\
&+ (1-\beta)\frac{\left(\nu - c + \sqrt{(\nu - c)^2 - \frac{1}{2}\alpha^{\ell\varrho}\gamma x^{\varrho*\,2}(2-\sigma)(1+\sigma)^2}\right)^2}{4(2-\sigma)^2(1+\sigma)}. \qquad (22)
\end{aligned}
$$

Equation (22) reveals immediately that the expected consumer surplus is increasing with the probability that the NGA succeeds. This is straightforward as a higher probability of success increases the investment incentives and the negative effect of increasing prices is dominated by the increasing reservation utility.

The expected consumer surplus with regulatory holidays is derived by substituting the equilibrium price (12) and the equilibrium investment (21) in the consumer surplus function with only one firm in the market, i.e. with linear demand:

$$
\begin{aligned}
E\left(CS^{RH}\right) =& \frac{\beta}{8}\left(\nu + x^{RH*} - c\right)^2 + \frac{(1-\beta)}{8}(\nu - c)^2 \qquad (23) \\
=& \frac{\beta}{8}\left(\nu + \frac{\beta(\nu - c)}{2\gamma - \beta} - c\right)^2 + \frac{(1-\beta)}{8}(\nu - c)^2. \qquad (24)
\end{aligned}
$$

Again, the expected consumer surplus increases with the probability of success. From Equation (22) and Equation (23) it follows that the expected consumer with regulatory holidays is lower than in the other regimes for a given investment level. Reconsidering the discussion and the simulations in the investment stage, it shows that *regulatory holidays* is always the worst regime from consumers' perspective, i.e. yield the lowest consumer surplus. This result is intuitive if we consider total output in the different regimes: as the access to the old network is not regulated in this setup, there is only one supplier in the market and total quantity should be (almost) always lower as in the case with two firms in the market. Consequently, total consumer surplus is lower if there is no competition in the market.

Given the results from the subsequent stages and that the first order conditions in the *LRIC* and *FD* regimes, i.e. Equation (17), do not provide closed-form solutions, it is ambiguous which regimes yield the highest consumer surplus. The *FD* regime yields the highest investment for most parameter range but also results in the highest expected prices for a given investment level. Cooperation yield the highest investment only for almost independent goods and a high probability of success of the NGA but yields the lowest expected prices for a given investment level. The *LRIC* regime performs moderately regarding the investment incentives and the expected price but seems important in order to create a sufficient willingness to cooperate. Hence, the net effect of the different regimes is ambiguous and does not provide further insights regarding the question which regime maximizes the social welfare. In order to get some further insights, I numerically simulated the consumer surplus in the different regimes. Figure 5 illustrates a simulation for the different parameter combinations for which the different regimes yield the highest consumer surplus. Note that this is *not* the sub-game perfect Nash equilibrium but the consumer surplus maximizing regimes if the regulator might choose the access regime, i.e. is able to enforce cooperation.

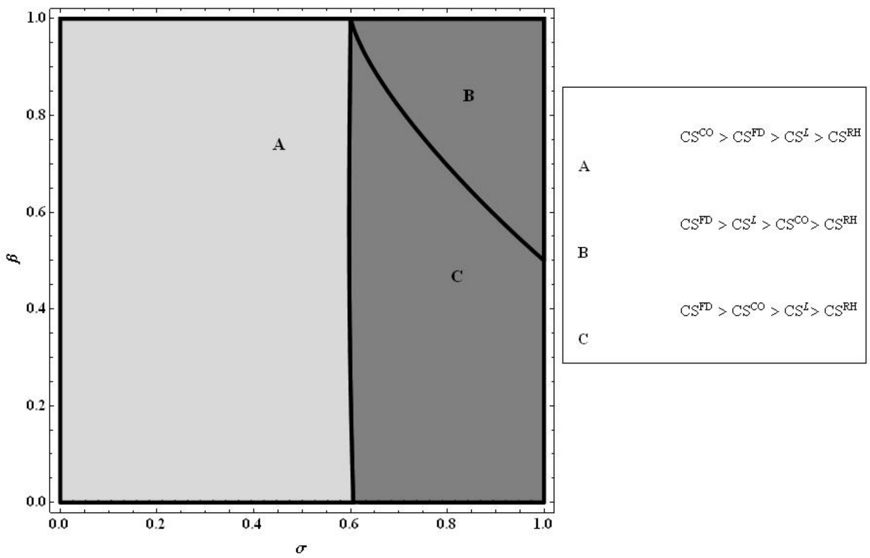


Figure 5: Relation of the expected consumer surplus in equilibrium subject to β and σ (for $\nu = 100$, $c = 20$, and $\gamma = 5$)

For a sufficiently high degree of product differentiation (a sufficiently low σ), cooperation yields the highest consumer surplus (regions A) whereas the *FD* regime maximizes the welfare if the products are closer substitutes (region B and C). Interestingly, the optimal policy is rather subject to the degree of product differentiation than to the probability of success. As discussed above, the simulation shows that regulatory holidays is the worst regime from the consumers' point of view. The $LRIC$ regulation always performs worse than the FD regime as long as there is some degree of product differentiation, i.e. $\sigma < 1$, and the success of the new infrastructure is not certain, i.e. $\beta < 1$. The comparison between the $LRIC$ regulation and cooperation shows that $LRIC$ might perform better if the products are close substitutes and the probability of success is high, i.e. for parameter ranges for which the firms will not agree to cooperate anyway. Intuitively, the relatively higher investment incentives with $LRIC$ in this parameter range dominate the positive effect of lower prices in the cooperation case. In opposite to NW's findings, there is no single regime which yields always the highest consumer surplus. The optimal regime is subject to the degree of product differentiation, an aspect which is not captured in NW's Cournot setup with homogeneous goods.

Remark 2. *Subject to the degree of product differentiation either the FD regime or cooperation maximize the consumer surplus.*

(i) For low to intermediate levels of product differentiation, cooperation yields the highest consumer surplus.

(ii) For intermediate to high levels of product differentiation, the FD regime maximizes the consumer surplus.

The first insight is that the optimal regulatory policy is, in particular, subject to the degree of product differentiation in the retail market. On the one hand, if we only consider telecommunications firms, i.e. firms with relatively homogeneous goods, the FD regime seems best. The symmetric risk allocation between both firms yield higher investment incentives. As competition is very intense in this case, i.e. retail prices are low, the negative effect of higher access costs on retail prices is less important and dominated by the higher investment incentives. On the other hand, we might consider firms from different markets or industries. As an example, one might think about a power supplier who asks for access in order to implement services related to smart grids. In this case, the $LRIC$ regime might be the best choice in order to create sufficient incentives for the firms to agree to a cooperation and the consumer surplus maximizing outcome might be realized based on the firms' private profit maximization incentive. The positive effect on competition due to the lower access costs, i.e. an access fee of zero, dominates the decreasing investment incentives in comparison with the FD regime. As discussed in the cooperation stage, this result is probably subject to the assumption that there are only two firms in the market or – if there are more than two firms – to the access conditions for late entrants. Another insight of the simulation of the expected consumer surplus is that high investment does not necessarily coincide with a high consumer surplus. A comparison of Figure 1 and Figure 5 reveals that the investment incentives and consumer surplus may fall apart. Even though the FD regime yield the highest investment for most parameter ranges, the higher prices and less intensive competition might dominate the positive investment incentive with symmetric risk allocation. Hence, the well-known trade-off between static and dynamic efficiency applies.

Total surplus Let us now analyze the case in which the regulator considers the producer surplus in its optimization process. Total expected welfare is then the sum of the consumer surplus and the aggregated producer surplus, i.e.

$$E(W^{\varrho}) = E(CS^{\varrho}) + E(\pi_I^{\varrho}) + E(\pi_E^{\varrho}).$$

As before, substituting the optimal prices and investment and simulating allows us to compare the welfare in the different regimes for different parameter combinations. Figure 6 illustrates the results of the numerical simulation. Again, this is not the sub-game perfect Nash equilibrium but the total surplus maximizing regime if the regulator might chose the access regime, i.e. is able to enforce cooperation.

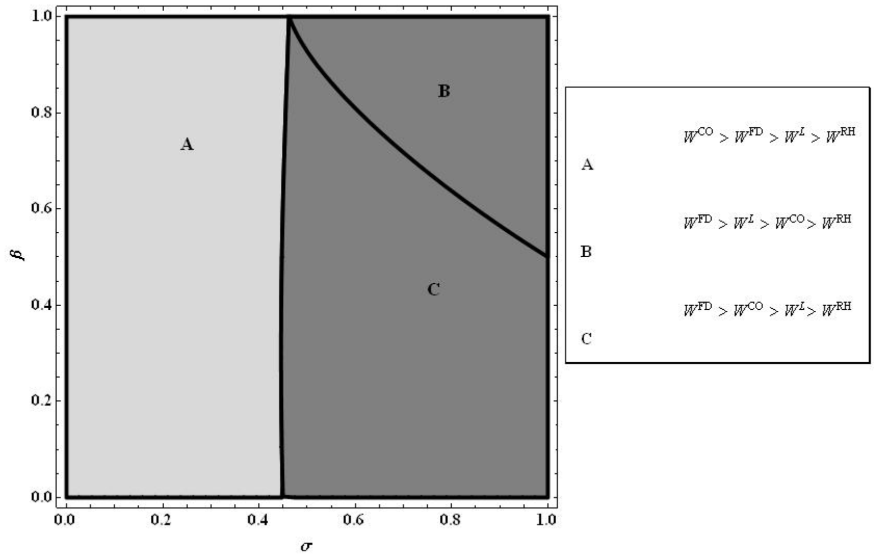
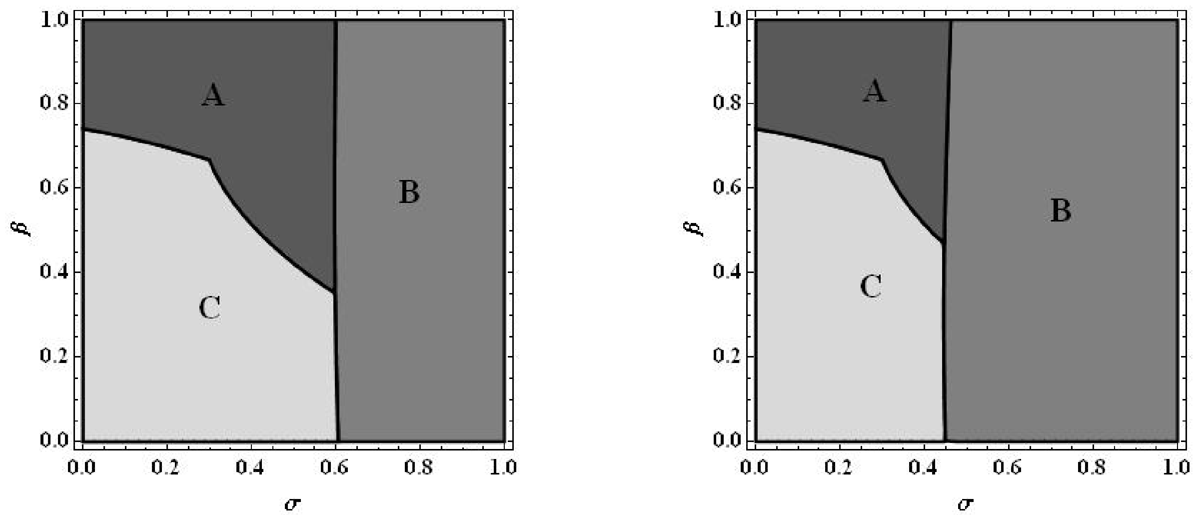


Figure 6: Relation of the expected welfare in equilibrium subject to β and σ (for $\nu = 100$, $c = 20$, and $\gamma = 5$)

Qualitatively, the results are the same as in the case in which the regulator only takes the consumer surplus into account. The range of parameter combinations for which cooperation yields the highest welfare decreases (region A) in comparison to the above case. The range for which full distribution of costs regulation is the welfare maximizing regime increases (regions B and C). Hence, if the regulator accounts for the producer surplus in its maximization problem, the *FD* regime becomes favorable for an increasing range of product heterogeneity. For intermediate degrees of product differentiation, the increasing profits of the firms with the *FD* regime dominate the decreasing consumer surplus compared to cooperation.

Equilibrium outcome So far, we only discussed the consumer and total surplus in case that the regulator might set the regime, i.e. is able to enforce cooperation. Let us now consider a case in which the regulator sets the access regime subject to the degree of product differentiation. If the products are sufficiently homogeneous and the *FD* regime is socially optimal, the regulator sets the *FD* access price. Otherwise, i.e. for more heterogeneous retail products for which cooperation would be socially optimal, the *LRIC* access prices applies. Note that "crucial" degree of product differentiation, for which the regulator sets the one or the other regime, differs subject to the maximization problem of the regulator, i.e. whether it maximizes consumer surplus or total surplus. Figure 7 illustrates the equilibria outcomes if the entrant bears 40 per cent of the investment costs in the cooperation case, i.e. $\mu = 0.4$.



(a) Consumer surplus (b) Total surplus

Figure 7: Equilibria subject to β and σ (for $\nu = 100$, $c = 20$, $\gamma = 5$, and $\mu = 0.4$)

Region *A* represents the parameter combinations in which cooperation would be the consumer or total surplus maximizing regime but for which at least one firm prefers the regulated access. From the regulator's perspective, cooperation is desirable in this parameter ranges but either the entrant, the incumbent, or both firms will not agree to jointly build the infrastructure. As a result, the realized regime for this parameter combinations is worse as the case with *FD* regulation. Region *B* represents the degree of product differentiation for which the regulator sets a *FD* access regulation. For this degree of product homogeneity, the incumbent always prefer regulated access to cooperation. In Region *C*, in which the investment risk is sufficiently high, i.e. β is sufficiently low, the firms will agree to jointly roll-out the infrastructure. The consumer or total surplus maximizing regime is realized as the private cooperation incentives, based on the profit maximization of firms, coincides with the socially desirable outcome. Note that it is not clear whether the implementation of *FD* regulation for all degrees of product differentiation or such a "differentiated" regulation based on the degree of product differentiation yields a higher consumer or total surplus. Hence, a remaining question is how cooperations might be fostered in these cases with heterogeneous goods and a high probability of success.

4 Conclusion

In this paper, I discuss the effects of four different access regimes on competition and investment incentives in NGA. The model compares two different regimes with access obligations, one with symmetric and one with asymmetric risk allocation, with a joint roll-out and an unregulated monopoly by adjusting the model from Nitsche & Wiethaus (2011). First, I implement price competition with horizontal product differentiation. Secondly, I interpret *NW*'s risk-sharing regime as cooperation between firms and analyzed explicitly whether and under which conditions firms might agree to jointly build the infrastructure.

The analysis reveals three main aspects: First, the objective to foster investment, e.g. to achieve specified coverage goals, might lead to situations in which the positive effect of increasing investment incentives is dominated by the negative effect on competition. High investment do not necessarily coincide with a high welfare and consumer surplus. The reason is that regimes which encourage investment via symmetric risk allocation imply higher access costs for all firms and consequently higher prices for the retail products even if the new infrastructure fails. The positive investment incentives of such a regime are then dominated by the negative price effect of investment and the risk of overinvestment arises. The consumer surplus increases due to increasing investment and decreases due to increasing prices and the net effect becomes negative. This is especially the case if retail products are very heterogeneous and the probability of a success of the NGA is low. Hence, the coverage goals discussed and predetermined by policy might yield an inferior market outcome from consumers' perspective if the focus is on the extent of NGA roll-out only and the gains from dynamic efficiency are dominated by the losses of static efficiency.

Secondly, the private incentives to cooperate might, at least partially, yield an outcome in which the firms' profit maximization also maximizes consumer surplus and total welfare. A crucial aspect in order to derive benefit from the private cooperation incentives is the provided outside option, i.e. the realized access regime, and the risk allocation between the firms. Subject to the implemented access regime, the private incentives to cooperate might be distorted such that the firms will not chose the consumer surplus maximizing regime. The results show that cooperation is superior to regulated access especially if firms provide differentiated goods. As a consequence, the focus of regulatory authorities and policy should be on actions to foster and to support cooperation between firms from different infrastructure industries. As the incentives to cooperate might differ between investing and access seeking firms, it seems reasonable to discuss additional instruments either to increase the willingness to cooperate, e.g. subsidization, or to create “soft pressure” on firms.

Thirdly, the optimal regulatory regime is subject to the probability of success of the new infrastructure but even more to the degree of product differentiation in the retail market. An access regulation with a symmetric risk allocation maximizes the surplus if the products are rather homogeneous whereas cooperation maximizes the surplus for rather heterogeneous products. As discussed, firms will in almost all cases only agree to cooperate if the regulator implements an access regulation with asymmetric risk allocation. Hence, regulatory authorities should probably put a higher weight on the type of firms seeking access to the new infrastructure. It might be favorable to provide firms from other infrastructure industries, e.g. for electricity suppliers who need access to telecommunication infrastructures in order to operate smart grids, different access conditions than competitors from the same industry.

A Appendix

A.1 Proof: For homogeneous goods, prices equal marginal costs

For homogeneous products, i.e. for $\sigma = 1$, equilibrium prices are given by

$$p_i^* = \frac{1}{2}\left(\nu + \psi x + c - \sqrt{(\nu + \psi x - c)^2 - 2\alpha^{\ell\varrho}\gamma x^2}\right).$$

The access fee $w^{\ell\varrho}$ in equilibrium equals

$$w^{\ell\varrho *} = \frac{\alpha^{\ell\varrho}\gamma x^2(2-\sigma)(1+\sigma)}{2(\nu + \psi x - c) + \sqrt{4(\nu + \psi x - c)^2 - 2\alpha^{\ell\varrho}\gamma x^2(2-\sigma)(1+\sigma)^2}}.$$

The firms marginal costs in the case of homogeneous goods are

$$MC = w^{\ell\varrho *} + c = \frac{\alpha^{\ell\varrho}\gamma x^2}{\nu + \psi x - c + \sqrt{(\nu + \psi x - c)^2 - 2\alpha^{\ell\varrho}\gamma x^2}} + c$$

and subtracting yields

$$p_i^* - MC = 0.$$

■

A.2 Proof of Proposition 1

The equilibrium prices are given by

$$p_i^{\ell\varrho *} = \frac{(c + (3-2\sigma)(\nu + \psi x)) - \sqrt{(\nu + \psi x - c)^2 - \frac{1}{2}\alpha^{\ell\varrho}\gamma x^2(2-\sigma)(\sigma+1)^2}}{2(2-\sigma)}$$

and expected prices by

$$E(p_i^{\varrho}) = \beta p_i^{S\varrho *} + (1-\beta) p_i^{F\varrho *}$$

with $\varrho = L, FD, CO$ and $i = I, E$.

Subtracting the expected prices in the different cases for a given investment level $x > 0$

yields

$$E(p_i^{FD}) - E(p_i^L) = \frac{(1-\beta)\left((\nu-c) - \sqrt{(\nu-c)^2 - \frac{1}{2}\gamma x^2(2-\sigma)(1+\sigma)^2}\right)}{2(2-\sigma)}$$

$$E(p_i^L) - E(p_i^{CO}) = \frac{\beta\left((\nu+x-c) - \sqrt{(\nu+x-c)^2 - \frac{1}{2}\gamma x^2(2-\sigma)(1+\sigma)^2}\right)}{2(2-\sigma)}$$

For $0 < \beta < 1$, both expressions are strictly positive and consequently $E(p_i^{FD}) > E(p_i^L) > E(p_i^{CO})$ applies. For a given investment level x, the expected quantities decrease with the expected prices and consequently $E(Q^{CO}) > E(Q^L) > E(Q^{FD})$ applies.

In the success case, subtracting the incumbent's price with regulatory holidays from the equilibrium price in the regimes with regulated access, i.e. with $\varrho = L, FD$, yields

$$p_i^{S\,\varrho} - p_I^{S\,RH} = \frac{(\nu+x-c)(1-\sigma) - \sqrt{(\nu+x-c)^2 - \frac{1}{2}\gamma x^2(2-\sigma)(1+\sigma)^2}}{2(2-\sigma)}.$$

Given our assumptions, this term is strictly negative if either $x = 0$ or

$$\sigma > \hat{\sigma} = \frac{(\nu+x-c)\left(\nu+x-c-\sqrt{(\nu+x-c)^2 - 2\gamma x^2}\right)}{\gamma x^2}.$$

Hence, it applies $p_I^{S\,RH} > p_i^{S\,\varrho}$ for $\sigma > \hat{\sigma}$.

In the success case, subtracting the incumbent's price with regulatory holidays from the equilibrium price with cooperation yields

$$p_i^{S\,CO} - p_I^{S\,RH} = -\frac{\sigma(\nu+x-c)}{2(2-\sigma)} < 0$$

and in the failure case

$$p_i^{F\,CO} - p_I^{S\,RH} = -\frac{\sigma(\nu-c)}{2(2-\sigma)} < 0.$$

Hence, the price in the cooperation case is always below the price in the monopoly case, i.e. $E(p_I^{RH}) > E(p_i^{CO})$.

In the failure case, subtracting the incumbent's price with regulatory holidays from the equilibrium price in the FD regime yields

$$p_i^{F\,FD} - p_I^{F\,RH} = \frac{(\nu - c)(1-\sigma) - \sqrt{(\nu-c)^2 - \frac{1}{2}\gamma x^2(2-\sigma)(1+\sigma)^2}}{2(2-\sigma)}$$

Given our assumptions, this term is strictly negative if

$$\sigma > \breve{\sigma} = \frac{(\nu - c)\left(\nu - c - \sqrt{(\nu-c)^2 - 2\gamma x^2}\right)}{\gamma x^2}.$$

Hence, it applies $p_I^{S\,RH} > p_i^{F\,FD}$ for $\sigma > \breve{\sigma}$.

In the failure case, subtracting the incumbent's price with regulatory holidays from the equilibrium price in the $LRIC$ regime yields

$$p_i^{F\,L} - p_I^{F\,RH} = -\frac{\sigma(\nu - c)}{2(2-\sigma)} \leq 0.$$

Consequently, $p_I^{F\,RH} \geq p_i^{F\,L}$ applies. ■

A.3 Proof of Proposition 3

$x^{CO*} > x^{L*}$ for $0 \leq \sigma < \tilde{\sigma}$ and $x^{CO*} \leq x^{L*}$ for $\tilde{\sigma} \leq \sigma \leq 1$

The first order conditions in the $LRIC$ regime and with cooperation for independent goods, i.e. for $\sigma = 0$, are given by

$$\begin{aligned}\left.\frac{\partial E(\pi_I^L)}{\partial x}\right|_{\sigma=0} =& \frac{\beta(\nu + x - c)}{4}\left(1 + \frac{\nu + x - c}{\sqrt{(\nu + x - c)^2 - \gamma x^2}}\right) \\ & - \gamma x \left(1 - \frac{\beta}{8}\left(5 - \frac{\nu + 2x - c}{\sqrt{(\nu + x - c)^2 - \gamma x^2}}\right)\right)\end{aligned}$$

and

$$\left.\frac{\partial E(\pi_I^{CO} + \pi_E^{CO})}{\partial x}\right|_{\sigma=0} = \beta(\nu + x - c) - \gamma x.$$

The optimal investment with cooperation and independent goods, i.e. for $\sigma = 0$, is therefore

$$x^{CO*}|_{\sigma=0} = \beta\frac{\nu - c}{\gamma - \beta}.$$

Substituting the optimal investment in the case of cooperation in the derivative of the profit function with *LRIC* and rearranging yields

$$-\frac{\beta(\nu-c)}{8(\gamma-\beta)}\left(\frac{\sqrt{\gamma}(\beta^2-\gamma(2-\beta))}{\sqrt{\gamma-\beta^2}}+\gamma(6-5\beta)\right)<0$$

As the first order condition with *LRIC* with the optimal investment level with cooperation x^{CO*} is strictly negative, the incumbent would chose a lower investment level and it applies $x^{CO*} > x^{L*}$ for $\sigma = 0$.

Now let us consider the case with perfect substitutes, i.e. $\sigma = 1$. The first order condition in both regimes are given by

$$\left.\frac{\partial E(\pi_I^L)}{\partial x}\right|_{\sigma=1} = -\gamma x(1-\beta)$$
$$\left.\frac{\partial E(\pi_I^{CO}+\pi_E^{CO})}{\partial x}\right|_{\sigma=1} = -\gamma x$$

If the retail goods are perfect substitutes, the only optimal investment in both regimes is $x^{CO} = x^L = 0$.

Now let us consider the slope of the first order conditions at the position $x = 0$, i.e.

$$\left.\frac{\partial^2 E(\pi_I^L)}{\partial x \partial \sigma}\right|_{x=0} = -\frac{4\beta(\nu-c)(1-\sigma(1-\sigma))}{(2-\sigma)^3(\sigma+1)^2}$$
$$\left.\frac{\partial^2 E(\pi_I^{CO}+\pi_E^{CO})}{\partial x \partial \sigma}\right|_{x=0} = -\frac{8\beta(\nu-c)(1-\sigma(1-\sigma))}{(2-\sigma)^3(\sigma+1)^2}$$

Obviously the slope of the first order condition is higher in the case with cooperation for $\beta > 0$. As a consequence, if we decrease σ marginally below 1, the investment incentive is higher in the case with *LRIC* and therefore $x^{L*} > x^{CO*}$ has to apply for $\sigma = 1-\epsilon$ with $\epsilon \to 0$.

From above arguments follows that the investment is higher in the *LRIC* regime if the goods are close substitutes and higher with cooperation if the goods are highly differentiated. Figure A.1 illustrates the optimal investment in both regimes subject to the degree of product differentiation.

Hence, given a probability β there exists a $\tilde{\sigma}(\beta)$ with $0 < \tilde{\sigma}(\beta) < 1$ for which both regimes yield the same investment levels and $x^{CO*} > x^{L*}$ for $0 \le \sigma < \tilde{\sigma}(\beta)$ and $x^{CO*} \le x^{L*}$ for $\tilde{\sigma}(\beta) \le \sigma \le 1$ applies.

$x^{CO*} > x^{RH*}$ *for* $0 \le \sigma < \check{\sigma} \approx 0.61$ *and* $x^{CO*} \le x^{RH*}$ *for* $\check{\sigma} \approx 0.61 \le \sigma \le 1$

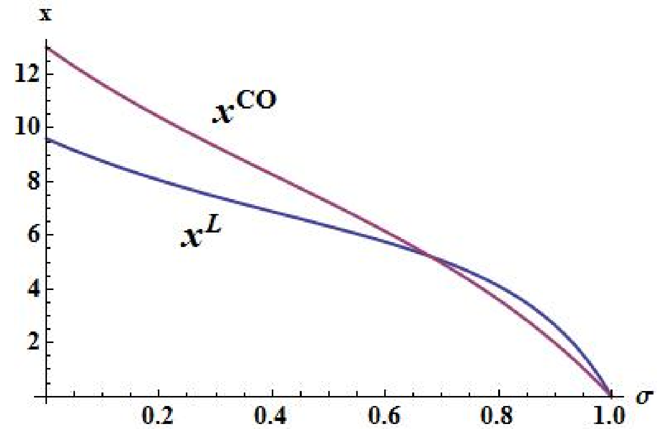


Figure A.1: Equilibrium investment with *cooperation* and *LRIC* subject to σ
(for $\nu = 100$, $c = 20$, $\gamma = 5$, and $\beta = 0.7$)

Subtracting the optimal investment with regulatory holidays from the optimal investment with cooperation yields

$$x^{CO*} - x^{RH*} = \beta(\nu - c)\left(\frac{4(1-\sigma)}{\gamma(2-\sigma)^2(1+\sigma) - 4\beta(1-\sigma)} - \frac{1}{2\gamma - \beta}\right)$$

For $\beta > 0$, $\nu > c$, and $0 \leq \sigma \leq 1$ the equation equals zero for

$$\sigma = \check{\sigma} = 1 + \frac{(2\sqrt{114} - 9)^{\frac{1}{3}}}{3^{\frac{2}{3}}} - \frac{5}{(3(2\sqrt{114} - 9))^{\frac{1}{3}}} \approx 0.6117$$

For $\sigma > \check{\sigma}$, the equation is strictly positive and for $\sigma < \check{\sigma}$ strictly negative and $x^{CO*} > x^{RH*}$ for $0 \leq \sigma < \check{\sigma} \approx 0.61$ and $x^{CO*} \leq x^{RH*}$ for $\check{\sigma} \approx 0.61 \leq \sigma \leq 1$ applies. ■

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