Network Investment, Access and Competition*

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Abstract

We analyze the role of different contract types and access regulation on innovation and competition in telecommunications in the context of Next Generation Access Networks. Within a standard duopoly model, we show that ex-post access contracts lead less often to the duplication of investment, but to a wider roll-out compared to a market in which such contracts cannot be offered. In comparison to such ex-post contracts, ex-ante contracts lead to an even wider roll-out, but to a less frequent duplication of investments. Ex-ante contracts in particular, but also ex-post contracts, can be used to dampen competition.

Keywords: Telecommunication, NGN, Access surcharge, Investment, Innovation, Contracts between network operators

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1 Introduction

Telecommunications markets are undergoing important changes as operators upgrade their access networks rolling out fiber instead of copper cables. *Next Generation Access Networks* (NGA) are essential to increase upload and download speed. This is key to encourage the development of new services for residential customers and businesses alike. The benefits for society and the private benefits for investors are, however, highly uncertain. Still, governments view the roll-out of high-speed connections as an important factor of competitiveness. High-speed connections come in various types: fiber to the home (FTTH), fiber to the building (FTTB), fiber to the premises (FTTP), and fiber to the cabinet (FTTC). While they differ by speed and investment cost, the economic issues involved are very similar.

After an investment has taken place, NGA infrastructure becomes an essential facility if duplication is not profitable. However, given high costs and uncertainty, even investment by only one network operator cannot be taken for granted. Whether investment incentives are appropriate depends on competition and on the type of contractual solution that networks use when granting or seeking access.

The aim of this paper is to shed more light on the precise role of the (possibly regulated) form of access contracts, together with competition, to generate investment incentives and benefits for consumers. In terms of regulation, our focus is on the regulation of the *form* and *timing* of such contractual solutions to share investment costs and to grant access, rather than on the regulation of the detailed clauses such as the access price. This allows, in particular, for market forces and bargaining power to determine these clauses. While this approach is currently not widely followed and we also discuss various cost-related access rules, regulation that focuses on the type of permissible contracts rather than the levels of access prices leaves more room for the market to determine access conditions and thus appears to be less intrusive. The main goal of this paper is to analyze investment incentives under alternative contracting regimes and market environments. In particular, we determine critical levels of investment costs above which investment in NGA is undertaken. We compare these critical levels across different contractual regimes.

Another issue is whether access terms can be used as a means to partially or even fully foreclose competitors. Based on our formal analysis, it appears that this concern should not be ignored, but that in differentiated product markets the incentive to foreclose competitors is limited. Instead of foreclosure, the problem may rather be that access contracts relax competition to the detriment of consumers.

Yet another issue that has been discussed in the policy arena are co-investments between operators. We refer to them as ex-ante contracts which are signed by parties before the investment is undertaken. One concern of those contracts is that they may impede effective competition in the market place. As we will argue, such a concern may be warranted. However, without further elaborating on this, ex-post interventions by regulators or antitrust authorities may reduce any risks of anticompetitive behavior.

We base our analysis on properties of equilibrium profits, which are satisfied by a standard "workhorse" model of Hotelling competition, albeit enriched by an extension that allows to capture different degrees of industry demand elasticity (see Section 3). We assume that both network providers have access to an "old" (copper) technology on equal terms. This holds either if both network providers own their own access network or if one obtains (regulated) access at marginal costs.[1] In this setting, we first derive, absent access contracts, some key insights on investment incentives and on how these interact with competition in the market (see Section 4). Subsequently, we allow for access contracts. Here, we first analyze ex-post contracts, which are contracts concluded only after the initial investment was made by one firm (Section 5). These are subsequently compared to ex-ante contracts in Section 6, which are signed before the investment decision is taken by at least one firm. These contracts can include co-investment agreements. Both ex-post and ex-ante access contracts can be used to dampen competition in the market for the new technology. We show how, depending on bargaining power, contracts may resolve differently a hold-up problem, on the one hand, and a possible foreclosure problem, on the other hand. Based on these results we can then compare ex-ante and ex-post contracts in terms of investment incentives. Access regulation is introduced in Section 7. We analyze how various forms of regulation impact on investment incentives and on competition. Section 8 concludes.

2 Related Literature

In our analysis we consider the interplay of competition, access contracts, and investment incentives. It appears that the link between access regulation and competition in downstream markets is not sufficiently considered in public discussions. However, we are not the first to have looked into this subject. In the following, we offer a brief, selective summary of the existing literature.

A significant literature on investment incentives started with Arrow (1962).[2] Several papers examine unbundled network access. Examples include Gual and Seabright (2000), a paper commissioned by the DGCOMP of the European Commission, and de Bijl and Peitz (2005), which outlines the economic issues of unbundling network access and the main regulatory challenges. A number of papers

[1] While interesting, it is beyond the scope of this paper to allow for asymmetries that arise from regulation of the old technology. For an analysis of asymmetries under the old technology see Bourreau, Cambini, and Dogan (2011) and Inderst and Peitz (2011a).

[2] For a discussion of this literature, see Belleflamme and Peitz (2010).

on one-way access focus on the optimal Ramsey-price setting of a regulator in an environment characterized by homogeneous services in the downstream markets. Other papers consider markets with a “competitive fringe”—i.e., a market in which there exists a horizontally or vertically differentiated incumbent and many small competitors, all of which offer perfectly substitutable services to each other. In earlier literature, authors have also considered the regulation of access fees for the case of given retail prices. In this context, it is worth mentioning the efficient component pricing rule (ECPR), thoroughly discussed in Armstrong (2002), as well as in Laffont and Tirole (2000) and Vogelsang (2003). A growing number of papers, as we do, focus on network access under imperfect competition. We will discuss some of these papers next.

Laffont and Tirole (1994) focus on the regulator’s problem in a Ramsey-price setting for the case of imperfect competition in the downstream market. Armstrong and Vickers (1998) consider an asymmetric market in which one of the two firms is more efficient. They show that regulators increase welfare by changing the terms of access in favor of the more efficient firm. The reason is that, otherwise, this more efficient firm will attain an insufficient market share from a social perspective; see also, Lewis and Sappington (1999). De Bijl and Peitz (2006) show that the effects of market regulation depend on whether the market is completely or partially covered—i.e., whether or not market demand is price-elastic. We have also examined this aspect in detail in this paper.

A significant part of the related literature comprises short-term analyses in which investments are considered already given. Valletti (2003) discusses investment incentives without explicitly modelling them. Guthrie (2006) provides an overview of the relevant literature, which establishes a connection between infrastructure investments and various regulatory regimes. Cambini and Jiang (2009) survey the theoretical and empirical research in the area of telecommunications, which examine connection between access, investments, and regulation.

Theoretical research papers that focus on unilateral network access and investment incentives include Foros (2004), Kotakorpi (2006), Vareda (2009a, 2009b), Klumpp and Su (2010), Brito, Pereira, and Vareda (2010), Nitsche and Wiethaus (2011), Bourreau, Cambini, and Dogan (2011), and Inderst and Peitz (2011a). What these papers have in common is their study of the incumbent’s incentives to improve the quality of its access network. Gans and Williams (1999), Gans (2001), Gans and King (2004), Hori and Mizuno (2006, 2009), and Vareda and Hoernig (2010) investigate the incentives in a race to build up a new access network. For the sake of brevity we provide some additional remarks on a few of these works.

Foros (2004) considers regulation as means to induce efficient investment incentives for a vertically integrated firm (typically the incumbent) and, at the same time, to prevent foreclosure to emerge. In a dynamic model with unregulated access, Bourreau and Dogan (2005) look at the effects of charges for unbundled network access on the incentives of the access-seeking firm to invest in an alternative network. Due to dynamic incentives, the incumbent grants free access to the market in order to postpone the setup of a competing network. Furthermore, the paper supports the idea that the incumbent may have no incentive to invest in the quality of its services. This result, however, only holds in a very unique model setting.[3]

Vareda (2009b) considers the interaction in a regulated market between the investments of an incumbent to increase the quality of its current network and the setup of an alternative NGA by a competitor. Vareda and Hoernig (2010) focus on investment competition between two firms, in which they allow for investment to bypass the access network. They show that two-part tariffs do not always suffice to obtain efficient investments in a first-best sense because the fixed part of the two-part tariff is supposed to fulfil two tasks: to optimize the timing of the investment of the first as well as of the second firm.

Nitsche and Wiethaus (2011) provide a detailed comparison of various regulatory instruments in a linear-quadratic model. In particular, they evaluate the instrument of regulatory holidays. Here, the authors assume that the investing firm does not grant access and, thus, there is complete foreclosure of the market. In their fully specified model they obtain a complete ranking of various regulatory instruments. However, it is questionable how robust their ranking is in a more general setting. While, to fix ideas, we also provide a fully specified model, we focus on robust implications and, thus, do not attempt to provide a welfare ranking of different contractual regimes.

Lastly, Bourreau, Cambini, and Dogan (2011) and Inderst and Peitz (2011a) focus on the role of initial asymmetries in the migration to NGAs. The former contribution provides a rich analysis of investment decisions in a continuum of markets, the latter is based on the present contribution to explore the importance of regulation-induced asymmetries in the market with the old technology on investment decisions in the new technology. Related to our Section 6, Bourreau, Cambini, and Hoernig (2011) provide a detailed analysis of co-investments in NGA.

3 The Duopoly Model

To fix ideas, we consider an extended Hotelling model with a hinterland for each firm. Our main insights are based on reduced-form profit functions and thus apply more generally. There are two network operators, firm 1 and firm 2 and

[3]On this topic, also see Pindyck (2007), as well as the discussion in De Bijl and Peitz (2002).

a continuum of consumers. Captive consumers of firm i are located in firm i's hinterland, and non-captive consumers are located on the Hotelling line.[4]

Firms and non-captive customers are located on the interval $[0, 1]$. Each non-captive consumer is represented through a location: $x \in [0, 1]$. More specifically, we assume that consumers are uniformly distributed on this interval, which gives rise to linear demand in the competitive segment of the market.[5] Also, we assume that the products of the two firms are located at the extreme points of the interval, 0 and 1. A consumer who is located at point x, has "transportation cost" τx when he purchases the product from firm 1 vs. $\tau(1 - x)$ when he purchases from firm 2. The parameter τ measures the level of horizontal differentiation and, thus, the degree of competition between the two offerings. We denote with u_i the gross utility of a consumer from the ideal service of firm i. The net benefit before deducting the purchasing price is $u_1 - \tau x$ when she purchases the product from firm 1 and $u_2 - \tau(1 - x)$ when she acquires the product from firm 2.

We assume that the mass of consumers M is situated on the $[0, 1]$-interval. In addition to this consumer segment, each firm has a "hinterland" with mass m_i of consumers, which it serves exclusively. This category of consumers is comprised of particularly loyal consumers with either high transition costs or strong preferences for a particular product. We assume that the hinterland is sufficiently unattractive and firm asymmetries are not too pronounced such that both firms have an incentive to serve the competitive segment of consumers.

Each firm sets the price p_i, which is valid for all consumers. A consumer of type x has net utility of $u_1 - \tau x - p_1$ when she consumes firm 1's product and net utility of $u_2 - \tau(1 - x) - p_2$ when she consumes firm 2's product. Firm i incurs costs of k_i per consumer it serves. We turn to possible investments in the following section.

3.1 Competition and Equilibrium

Within the competitive segment, there is a consumer type $\widehat{x}$ who is indifferent between the service offered by the two firms, $u_2 - p_2 - (1 - \widehat{x})\tau = u_1 - p_1 - \widehat{x}\tau$. Then

$$\widehat{x}(p_1, p_2) = \frac{1}{2} + \frac{1}{2\tau}\left[(u_1 - p_1) - (u_2 - p_2)\right].$$

[4] If a firm has captive customers this firm is essential to provide services to this group of customers. The larger the number of captive customers of this firm, the less likely that foreclosure of that firm is an issue.

[5] The assumption of a uniform distribution is made for computational convenience. Our results can be extended to other well-behaved customer distributions.

All consumers located to the left of $\widehat{x}$ will buy product 1, while all consumers located to the right of $\widehat{x}$ will purchase product 2. The demand of each firm is

$$q_1 = m_1 + M\widehat{x} \text{ and } q_1 = m_2 + M(1-\widehat{x}).$$

Hence, before subtracting fixed costs, firm 1's profit is

$$\pi_1 = (m_1 + M\widehat{x})\,(p_1 - k_1)\,.$$

Analogously, firm 2's profit is:

$$\pi_2 = (m_2 + M(1-\widehat{x}))\,(p_2 - k_2)\,.$$

It proves useful to define the following parameters: $\widehat{m}_1 = m_1/M$ and $\widehat{m}_2 = m_2/M$. Hence,

$$\pi_1 = M\,(\widehat{m}_1 + \widehat{x})\,(p_1 - k_1) \;\text{ and } \pi_2 = M\,(\widehat{m}_2 + (1-\widehat{x}))\,(p_2 - k_2)\,.$$

Thus, the factor M scales the size of the (regional) markets.

Each firm sets its price so that, given its competitor's price, its profit is maximized. A necessary condition for profit maximization is that the marginal profit is zero. As derived in Appendix 1, equilibrium profits can be expressed as,

$$\begin{aligned}
\pi_1^* &= M\frac{1}{2\tau}\left(\frac{1}{3}(u_1-u_2)+\frac{1}{3}(k_2-k_1)+\frac{2\widehat{m}_2}{3(1/\tau)}+\frac{4\widehat{m}_1}{3(1/\tau)}+\tau\right)^2, \\
\pi_2^* &= M\frac{1}{2\tau}\left(\frac{1}{3}(u_2-u_1)+\frac{1}{3}(k_1-k_2)+\frac{2\widehat{m}_1}{3(1/\tau)}+\frac{4\widehat{m}_2}{3(1/\tau)}+\tau\right)^2.
\end{aligned}$$

In Appendix 1 we report further variables of interest, in particular, equilibrium prices and welfare.

3.2 Price-Dependent Industry Demand

In our previous analysis, a central assumption was that industry demand was price-independent. We now suppose that demand in both monopoly segments is price-dependent—i.e., $m_1(p_1)$ is decreasing in p_1 when positive and $m_2(p_2)$ is decreasing in p_2 when positive. In particular, set $m_i(p_i) = \max\{0, \mu_i(a_i + u_i - b_i p_i)\}$. Then, firm 1's demand is

$$q_1 = M\left[\frac{1}{2} + \frac{1}{2\tau}\left[(u_1 - p_1) - (u_2 - p_2)\right] + \mu_1(a_1 + u_1 - b_1 p_1)\right].$$

Appendix 2 reports equilibrium prices when hinterlands are symmetric.

4 Investment Incentives in the Absence of Contracts

4.1 Initial Observations

Technologies Investments can both reduce costs and increase customer valuation. Within the NGA context investments that increase the product's valuation appear to be particularly relevant. Therefore, we suppose that a firm's investment volume I_i positively affects a customer's valuation u_i.

We consider a 0-1 investment decision in the build-up of an NGA access network. This appears to be the relevant case if markets are regionally segmented—i.e., a firm decides whether or not it will invest in a new technology in a particular region and that this is unaffected by its decisions in other regions.[6]

We further assume that a firm that does not invest, uses the old technology.[7] A firm i, which has not invested, is characterized by $u_i = u^O$ and $k_i = k^O$ (the "old technology"). An investment amounting to I_i generates a more attractive offer $u_i = u^N > u^O$ (the "new technology"), e.g., through faster uploads and downloads. Moreover, the cost per participant can also change, from k^O to k^N, which could be higher or lower.

Investment Incentives We can write profits as a function of whether firms 1 and 2 have invested: $\pi_1^*(d_1, d_2)$ and $\pi_2^*(d_1, d_2)$, where we set $d_i = 1$ when firm i has made an investment and $d_i = 0$ when it has not. In the case of price-independent industry demand, explicit expressions for these profits have been derived in the previous section.

If the other firm does not invest, such an investment is profitable when the change in profits after deduction of investments costs is positive. That is,

$$I_i \leq I_i^* \equiv \pi_i^*(1,0) - \pi_i^*(0,0).$$

If the other firm also invests, the investment is profitable if

$$I_i \leq I_i^{**} \equiv \pi_i^*(1,1) - \pi_i^*(0,1).$$

This condition is stricter than the previous one—i.e., $I_i^{**} < I_i^*$. Profit growth is smaller if the competitor is expected to invest also.

[6] Thus, we do not need to consider coverage decisions. If an operator had to set a uniform price across regions our analysis would need to be modified. We refer to Bourreau, Cambini and Dogan (2011) for an analysis where firms price-discriminate between regions.

[7] As noted in the introduction, if one firm requires access to the old technology and the other firm upgrades its network, the access option for the old technology may no longer be available. We refer to Inderst and Peitz (2011a) for an analysis of such a situation.

If $m_1 = m_2$ (so that $I_1^* = I_2^* \equiv I^*$ and $I_1^{**} = I_2^{**} \equiv I^{**}$), we distinguish between three regimes:[8]

1. $I \leq I^{**}$: The necessary volume of investment is so small that both firms have an incentive to invest, irrespective of the competitor's investment decision.

2. $I^{**} < I \leq I^*$: The investment pays off only if the competitor does not invest.

3. $I > I^*$: The necessary volume of investment is so high that no firm has an incentive to invest, irrespective of the competitor's investment decision.

In the first case, in subgame-perfect equilibrium of the investment-then-pricing game both firms invest at the first stage. In this case, it is possible that $\pi_i^*(1,1) - I < \pi_i^*(0,0)$. This corresponds to the prisoner's dilemma problem: If both firms could write binding contracts, they would agree not to undertake their investments. But since they cannot cooperate when taking this decision, they both invest and attain lower profits than in the initial situation. If we allow for asymmetries between firms, from the general considerations about investment incentives, we conclude that the firm with the higher initial market share has higher incentives to invest, and, thus, that the thresholds (I_i^* and I_i^{**}) are smaller than those of its competitor.

Welfare Duplicating investments has several effects. First, fixed costs will be duplicated. As long as the firm that has invested does not grant its competitor access to the network, duplication is the only way to provide higher-quality services to those consumers who are served by the competitor. An investment by one firm increases its returns given the investment decision of the other firm. Second, investment decisions influence competition in the market: Competition is asymmetric when just one firm invested, while it is symmetric when both firms invested. Third, with price-dependent industry demand, a firm's investment affects the deadweight loss of the corresponding hinterland (where the size of the deadweight loss depends on the prices that are set in equilibrium).

Let us consider the social desirability of investment duplication. For the sake of simplicity, we address this issue only for the special case that there are no hinterlands—i.e., $m_1 = m_2 = 0$. We use the following notation: $\widehat{x}(1,0)$ denotes the

[8] For the purpose of this analysis, we abstract from mixed-strategy equilibria, which could be interpreted as arising from a coordination failure. This may be justified also on the following grounds: Planning and implementation of investment should extend over a longer period of time. Then a coordination failure seems less plausible, even though this is modelled in the game as a one-off decision. (Furthermore, if one instead assumes that firms decide whether to invest in an exogenous sequence, there is a unique pure-strategy equilibrium: It never happens in a subgame-perfect equilibrium that the second mover invests if the first mover has not invested.)

indifferent consumer if firm 1 invests and firm 2 does not. Analogously, we define $\widehat{x}(0,0)$, $\widehat{x}(0,1)$, and $\widehat{x}(1,1)$. We denote total surplus depending on the number of firms which have invested, n, by $W(n)$. If just firm 1 invests, welfare is

$$W(1) = M\left[\widehat{x}(1,0)(u^N - k^N) + (1-\widehat{x}(0,1))(u^O - k^O) - T(\widehat{x}(0,1))\right] - I.$$

If both firms invest, welfare is

$$W(2) = M\left[(u^N - k^N) - T(\widehat{x}(1,1))\right] - 2I.$$

To see whether the market can feature socially excessive investment duplication, we evaluate welfare at the critical investment threshold I^{**}. If $W(1) > W(2)$ holds at I^{**}, it would be more efficient to suppress the investment of the second firm. Without loss of generality, set the market size equal to $M = 1$. From the previous analysis, it follows that $\widehat{x}(1,1) = 1/2$ and $\widehat{x}(1,0) = 1/2 + \Delta/(6\tau)$, where $\Delta \equiv (u^N - k^N) - (u^O - k^O)$ is the cost-adjusted difference in utilities between the new and the old technology. Thus both firms remain active if $\widehat{x}(1,0) < 1$ which is equivalent to $\tau > \Delta/3$. The critical investment volume is $I^{**} = \Delta^2/(18\tau) - \Delta/6$. Hence, the difference in welfare, evaluated at this level, is

$$\begin{aligned} W(2) - W(1) &= (1-\widehat{x}(1,0))\Delta + T(\widehat{x}(1,0)) - T(\widehat{x}(1,1)) - I^{**} \\ &= \left(\frac{1}{2} - \frac{1}{6\tau}\Delta\right)\Delta + \left(\frac{\tau}{2}\left(\frac{1}{2} + \frac{1}{6\tau}\Delta\right)^2 + \frac{\tau}{2}\left(\frac{1}{2} + \frac{1}{6\tau}\Delta\right)^2\right) - \frac{\tau}{4} \\ &\quad - \left(\frac{1}{18\tau}\Delta^2 - \frac{1}{6}\Delta\right) \\ &= \frac{2}{3}\Delta - \frac{7}{36}\frac{\Delta^2}{\tau} > 0 \end{aligned}$$

for $\tau > \Delta/3$. We observe that for any admissible value τ, the expression is positive. Thus, in this simple specification, investment duplication is never socially excessive if network access is not feasible or prohibited by the regulator.

5 Investment under Ex-Post Contracts

5.1 Price-Independent Industry Demand

Linear Access Contracts In this section, we consider contracts that grant the competitor access to the constructed network and that are concluded after the investment. Before considering more complex contracts, we first consider *linear* contracts—i.e., the competitor receives access to NGA and pays an access surcharge per customer. For the moment, we further assume that the investing firm holds all the bargaining power. Specifically, we consider the case in which firm 1 has made an investment while firm 2 has not, and the latter decides whether to take the offer to gain access through paying an access fee w per customer.

Decisions are taken as follows: After firm 1 has invested, but firm 2 has not, firm 1 offers a contract w that specifies the price for which firm 2 can get access for each of its additional customers. Subsequently, both firms set their prices. Profit functions are

$$\begin{aligned}
\pi_1(p_1, p_2; w) &= (p_1 - w)(M\widehat{x}(p_1, p_2) + m_1) + (w - k^N)(M + m_1 + m_2), \\
\pi_2(p_1, p_2; w) &= (p_2 - w)(M(1 - \widehat{x}(p_1, p_2)) + m_2).
\end{aligned}$$

An important result is that because industry demand is price-independent (the number of customers is always $M + m_1 + m_2$), the level of w does not impact equilibrium profits of firm 2.[9] Thus, in the standard model, the specific design of the linear contract is irrelevant for firm 2 (as shown in de Bijl and Peitz, 2006). This insight is now discussed in detail. An increase of w by Δw results in a price increase for both firm 1 and firm 2. In this model, the firm with granted access passes on the entire increased costs of access to consumers. The firm granting access also increases its price, although its costs k^N remain unchanged. The reason for this is that its opportunity costs have also increased by Δw as each lost customer generates additional profit of Δw in the access market. The economic costs for both firms have therefore increased by Δw.

In comparison to a market without contracts, we observe that firm 1 has increased its profits compared to $\pi^*(1, 0)$. In the model with access, profits of the access-seeking firm are equal to $\pi^*(1, 1)$. However, it does not need to make investments itself. Therefore, firm 2 will always prefer not to invest itself, but to use the access network of its competitor. This holds true despite firm 1 having full control over the price of access.

If we now consider investments at the upstream stage and, for simplicity, assume sequential investments, there does not exist an equilibrium in which firm 2 also invests - i.e., there is no duplication of the access network. We now have a new critical value I_P^*, below which firm 1 decides to invest. If I exceeds this threshold, there is no investment at all. The critical value I_P^* is greater than I^*. This is true because the access-granting firm can extract rents amounting to $(M + m_1 + m_2)(w - c)$ when w was chosen optimally ensuring that the market is still fully covered. Figure 1 below illustrates these findings.

[9] More precisely, this holds until an upper bound, above which some customers are no longer active. Thus, firm 1's maximization problem must satisfy the condition that, when setting w, this upper bound is not exceeded.

More Complex Access Contracts Up to this point, we have only considered linear contracts, implying that the access-seeking firm pays the same price per user. In principle, this does not have to be true. For example, a contract can comprise the payment of a fixed fee together with a smaller additional variable fee. This way, the firm granting access to the network can achieve further rent extraction. In our case, in which the firm granting access has full bargaining power, it can even extract the entire rent and therefore lower the profit of the access seeking firm to the level without access: $\pi^*(0,1)$. In more concrete terms, this means that the contract then includes an additional fixed user fee amounting to $F = \pi^*(1,1) - \pi^*(0,1)$.

This has now repercussions on incentives to invest. The case in which none of the firms invests becomes less likely: The corresponding threshold under non-linear contracts, $I^*_{P,NL}$, lies strictly above the previous threshold: $I^*_{P,NL} > I^*_P > I^*$. On the other hand, there now exists an interval in which both firms invest: $I \leq I^{**}_{P,NL}$. As in the current case, where the access-granting firm has the entire bargaining power, the non-investing firm stays at the same profit level of $\pi^*(0,1)$, this threshold is the same as without contracts: $I^{**}_{P,NL} = I^{**}$.

Bargaining Power As long as we consider only linear contracts, the distribution of bargaining power plays *no* role. Both firms are strictly better off if w is chosen as to reach the monopoly outcome.[10] The distribution of bargaining power, however, plays a very important role under more complex contract schemes.

Complex contracts allow us to analyze two objectives of contracts separately and without any conflicts. The first is to maximize *aggregate* industry profits. Within the current framework, this is achieved by choosing w high enough to attain the monopoly outcome. The second objective is to divide the resulting profits according to the corresponding bargaining power of both parties. Both objectives can already be reached with a two-part tariff (F, w). Then shifts in bargaining power have no effect on the market outcome given investments, but only for the distribution of rents between both firms. This, however, has repercussions on incentives to invest. If the access-seeking firm has bargaining power, thresholds for investment shift as follows. If only one firm invests, the new threshold $I^*_{P,VH}$ will lie below the previous threshold $I^*_{P,NL}$ due to the emerging hold-up problems (which occurs because the non-investing firm can now retain some rents).[11] On the other hand, the probability of a duplication of investments again decreases: $I^{**}_{P,VH}$ lies below $I^{**}_{P,NL}$. It also holds that $0 = I^{**}_P < I^{**}_{P,VH} < I^{**}_{P,NL}$ and $I^* < I^*_P < I^*_{P,NL}$, as well as $I^* < I^*_{P,VH} < I^*_{P,NL}$. In general, it is not clear whether $I^*_P < I^*_{P,VH}$ as, in

[10] Furthermore, this holds under the assumption that it is always optimal to reach full coverage of the entire market.

[11] For a seminal formal analysis of the hold-up problem, we refer to Grossman and Hart (1986).

extreme cases, the non-investing firm can push down profits of the investing firm to $\pi^*(1,0)$. Fig. 1 sums up the equilibrium investment decisions in all four scenarios. A stronger bargaining position of firm 2 leads to less duplication of investments because firm 2 can alternatively enforce a more attractive contract for itself.

< insert Fig 1 around here >

5.2 Price-Dependent Industry Demand and Access Charges

Linear Access Contracts Our previous analysis essentially depended on the assumption that industry demand is price-independent. In the following, we analyze price-dependent demands in the monopoly segments—i.e., $m_1(p_1)$ is decreasing in p_1 and $m_2(p_2)$ is decreasing in p_2. The special case with constant $m_1 = 0$ and linear contracting was investigated by de Bijl and Peitz (2006).

The profit function of firm 1 is now

$$\begin{aligned} \pi_1 &= (p_1 - k^N)(M\widehat{x}(p_1,p_2) + m_1(p_1)) + (w - k^N)(M(1-\widehat{x}(p_1,p_2)) + m_2(p_2)) \\ &= (p_1 - w)(M\widehat{x}(p_1,p_2) + m_1(p_1)) + (w - k^N)(M + m_1(p_1) + m_2(p_2)). \qquad (1) \end{aligned}$$

The profit function of firm 2 is

$$\pi_2 = (p_2 - w)(M(1-\widehat{x}(p_1,p_2)) + m_2(p_2)).$$

Both equilibrium prices p_1^* and p_2^* depend on w. In contrast to the basic model with price-independent industry demand, in this framework, it holds that $dp_2^*/dw < 1$, since an increase in price will lead to reduced demand in the monopoly segment. This implies that a higher NGA access fee induces lower profits for the access-seeking firm. Correspondingly, firm 1 will adjust its price such that $dp_1^*/dw < 1$ holds despite its increased opportunity costs.

However, with price-dependent industry demand we now have the following important asymmetry between the two firms: Firm 1 has an opportunity cost of k^N when selling to additional consumers in its monopoly segment. Firm 2, however, incurs the cost for access $w > k^N$ in its own monopoly segment. In equilibrium, firm 1 will now tend to set a lower price as its opportunity costs are lower compared to its competitor. As a consequence, we will have *partial market foreclosure*: A higher access price w will lead to asymmetric market outcomes resulting in decreasing market share of the access-seeking firm.

The basic model with price-independent industry demand is of key importance, as it shows that in case of asymmetric investments the investing firm has no incentives to foreclose the market. Therefore, we should not always suspect that there exist incentives for a complete or partial market foreclosure. With price-dependent industry demand, however, the access-granting firm secures a higher market share. Effectively, it raises the rival's costs reducing the rival's market share, and this may be labelled as partial foreclosure. As a result, duplication of investments can occur even in case of linear contracting. At least in the game we consider, in which the access-granting firm holds all the bargaining power, the other firm, even with linear contracts, turns out to be strictly worse off compared to the a situation in which it had invested itself from the beginning (abstracting from fixed investment costs).

More Complex Access Contracts and Bargaining Power In the case of price-dependent industry demand, more complex contracts are also useful to achieve a generally more efficient outcome. In order to illustrate this, we again consider the case in which the access-granting firm has full bargaining power and makes a take-it-or-leave-it offer.

From above we know that with price-independent industry demand, a linear access tariff w grants the access-seeking firm profit $\pi^*(1,1)$, which exceeds $\pi^*(0,1)$. Qualitatively, the same result holds with price-dependent industry demand. Of central importance is the following observation: As previously mentioned, with a linear access fee, the fee w determines *both* the size of the industry profits *and* their distribution. In the case of price-dependent demand, given the optimal choice of w of the access-granting firm, we obtain equilibrium prices that may differ from those chosen by an integrated monopolist. Even in a symmetric baseline scenario the price set by the access-seeking firm is higher and its market share smaller, especially compared to the monopoly outcome. If, however, the access-granting firm can also set a fixed fee F, it will charge a smaller unit price w in order to extract a higher rent with the fixed fee. In a nutshell: With a complex access contract double marginalization may be prevented.

This result remains valid even if bargaining power is differently distributed. If the contract is sufficiently complex, the (marginal) unit price w and the final customer price are independent of the distribution of bargaining power, which just causes a shift of rents between the firms. The situation is different in case of linear tariffs. There, given that industry demand is price-dependent, an increase in the bargaining power of the access-seeking firm will lead to a reduction in w and, hence, to lower prices for both firms as well as a higher market share for the access-seeking firm.

Our discussion should, however, not hide the fact that complex access contracts can be to the detriment of consumers. To see this, first recall that the two-part tariff (F, w) does not achieve the monopoly outcome. Let us, instead, consider a more general contract that links payments of the access-seeking firm to the sales volume of both firms. As an example under symmetry, consider the following simple tariff system implementing the monopoly outcome given an arbitrary distribution of bargaining power. First, the access-seeking firm makes a fixed payment F to the access-granting firm. Second, assume that after the realization of quantities a fixed fraction of the lump-sum payment, K, is divided between the two firms proportionally to their quantities such that the split is $q_1K/(q_1+q_2)$ and $q_2K/(q_1+q_2)$, respectively. By choosing K appropriately, we can now steer the marginal costs of both firms in such a way that the monopoly outcome is obtained. The fixed fee F can then be used to generate an asymmetric rent distribution between the two firms.

5.3 Summary: Ex-Post Contracts

Let us compare the case with ex-post contracts with the one in which firms could not conclude contracts. The following results follow from the above analysis:

Result 1. With (ex-post-) contracts, at least one of the firms invests more often than without contracts. This holds even more if the bargaining power lies with the access-granting firm and if complex access contracts can be used.

Result 2. With (ex-post-) contracts, situations in which both firms invest (duplication of investments) are less frequent. This is less often the case if the access-seeking firm has a much bargaining power. Complex contracts are more likely to lead to duplication, especially if bargaining power resides with the access-granting firm.

Customers benefit from duplication of investments since then competition is more intense. If only one firm invests, all customers can still access the new technology if such access is granted. On the other hand, such an access contract can be used to dampen competition, so that customers could theoretically be worse off compared to a situation in which none of the firms invested but price competition remained intact. A reduction of competition may, however, be sometimes necessary as, otherwise, an investment may not be profitable. A key element in the overall assessment of ex-post contracts is thus the question whether some reduction in the degree of competition, either through avoiding duplication of investments or through a dampening of competition by contractual means, must be tolerated to maximize social and consumer surplus.

6 Investment under Ex-Ante Contracts

6.1 Bargaining and Ex-Ante Contracts

We now consider the possibility that both firms can agree upon long-term contracts for the joint use of a new technology before the actual investment is made. These contracts can be seen as co-investment contracts.

Let us first focus on the phase of negotiation. We do not model the bargaining process itself, but postulate that bargaining is efficient (according to the view of the two firms involved) and that the symmetric Nash bargaining solution is achieved, i.e., that the gains relative to the outside options are equally split.[12] To determine the outcome of these negotiations, we first have to determine the consequences if ex-ante negotiations are unsuccessful. In particular, what are the equilibrium profits firms would achieve in case ex-ante negotiations break down? These profits constitute the outside options of the two firms. Let us denote these outside options by π_1^{BD} and π_2^{BD} (here, BD stands for "breakdown"—i.e., failure of negotiations). In order to have a unique prediction assume for simplicity that one of the firms, say $i = 1$, decides at first whether it wants to invest (This is consistent with a modified model of sequential investment). For this situation, we have already characterized the equilibrium with the threshold values I^* and I^{**} in the case without contracts. Now suppose for the moment that ex-post contracting is not feasible. Then, if $I^* < I$ and profits are symmetric, it holds that $\pi_i^{BD} = \pi^*(0,0)$ since neither of the firms invests in case of a failure of ex-ante negotiations. If $I^{**} < I < I^*$ so that exactly one firm invests in a situation without contracts, it follows that $\pi_1^{BD} = \pi^*(1,0) - I$ and $\pi_2^{BD} = \pi^*(0,1)$. If $I < I^{**}$ so that both firms invest in a situation without contracts, it follows that $\pi_1^{BD} = \pi^*(1,1) - I$ and $\pi_2^{BD} = \pi^*(1,1) - I$.

What happens to ex-post contracting in case of a failure of ex-ante negotiations? Depending on the choice of a particular ex-post contract, the above thresholds are adjusted accordingly—for example, to thresholds $I^*_{P,NL}$ and $I^{**}_{P,NL}$ in the case of non-linear ex-post access contracts.

We assume that contracts are flexible enough so as to allow a separation of rent distribution and industry profit maximization. As an example, if we consider two-part tariffs (F, w), the per-consumer wholesale payment w will be chosen inde-

[12]Ex-ante and ex-post contracts differ with respect to the point in time they are signed, before or after the investment. This implies that, under ex-post contracting, the investment generates an asymmetry between firms. An extreme assumption, which was the starting point of our analysis in the previous section, is that the access-granting firm has all the bargaining power. By contrast, under ex-ante contracting it is endogenous which of the firms will carry out the investment. Thus, the Nash bargaining solution appears to be the natural starting point of the analysis under ex-ante contracting.

pendent of the distribution of bargaining power in order to maximize total industry profits. The fixed payment F is used to divide the rent among the two firms. Denote the industry profits attainable under the optimal access contract (i.e. only one firm invests) by Π_M^N (gross of investment costs). It follows that the "net surplus" generated by the investment of a firm equals

$$NS = (\Pi_M^N - I) - (\pi_1^{BD} + \pi_2^{BD}).$$

If $I^{**} < I < I^*$, this becomes

$$\begin{aligned} NS &= (\Pi_M^N - I) - [\pi^*(1,0) + \pi^*(0,1) - I] \\ &= \Pi_M^N - [\pi^*(1,0) + \pi^*(0,1)]. \end{aligned}$$

If $NS > 0$ and firms have the same bargaining power, the value of the fixed payment F is determined so that each firm has an equal share of net surplus NS. Firm 1 would receive, for example, $\pi_1^{BD} + NS/2$. For the case when $I^{**} < I < I^*$, firm 1 would realize a profit of

$$[\pi^*(1,0) - I] + \frac{1}{2}\left[\Pi_M^N - \pi^*(1,0) - \pi^*(0,1)\right].$$

For firm 2, we end up with a profit of $\pi_2^{BD} + NS/2$, respectively, or, explicitly for the case $I^{**} < I < I^*$:

$$\pi^*(0,1) + \frac{1}{2}\left[\Pi_M^N - \pi^*(1,0) - \pi^*(0,1)\right].$$

6.2 Investments

It is important to understand the implications of ex-ante contracts on the willingness of firms to invest in comparison to an environment in which only ex-post contracting is allowed or feasible. In case of price-independent industry demand it always follows—and is, therefore, independent of the available access contracts—that duplication of investments does not occur: $I_A^{**} = 0$ with ex-ante-contracts. However, we may still have duplication of investment with price-elastic industry demand under ex-ante contracting, provided that these access contracts cannot be sufficiently flexibly designed.

At the same time, ex-ante contracts mitigate the hold-up problem or in the case of sufficiently complex contracts even allow to avoid it completely.[13] For this reason, the threshold I_A^* lies above the corresponding threshold that would apply

[13] As a reminder: The hold-up problem arises when the single investing firm cannot extract the full rent created by the investment due to some ex-post bargaining power of the access-seeking firm.

if only ex-post contracts were allowed. Fig. 2 illustrates the investment behavior of firms acting in markets with price-independent industry demand depending on the particular contracting environment.

< insert Fig. 2 around here >

Consequently, we obtain the following results:

Result 3. If ex-ante contracts are feasible, then at least one firm invests more frequently as under either only ex-post contracts or no contracting at all.

Result 4. With ex-ante contracts, duplication of investments occurs less often.

As already pointed out in our previous discussion of the implications of ex-post contracts, we again come to the conclusion that the avoidance of duplication can harm consumers. Consumers can, however, benefit from ex-ante contracts, provided these contracts make investments economically profitable in the first place.[14]

7 Implications for Regulation

This paper focuses on the allocative implications of different contracting regimes. Regulators (and courts) may discourage or even prohibit certain contracting regimes. For instance, regulators may rule out cost-sharing contracts at an ex-ante stage—i.e., they may effectively prohibit ex-ante contracts. The allocative consequences of such an intervention follow directly from the analysis above.

Regulators may also intervene and impose certain contractual clauses with respect to access. In particular, they may impose particular access prices. Here we shortly discuss the implications of our framework for access regulation. This part of the analysis is less original, since previous work has looked at one-way access regulation before (see the references in Section 2).

Here, our analysis suggests a standard potential conflict between the creation of higher investment incentives and competition after the initial investment. For

[14] One aspect we have not yet covered in our model is the availability of a new technology in the future that further intensifies competition. If access to the forerunner technology is essential to using the newly available technology, this market exhibits the property of a ladder of investment—i.e., investment in the current technology is spurred, as otherwise the future technology is not available. In this case, ex-ante contracts have the disadvantage for the access-granting firm that it, figuratively speaking, nurtures a future competitor to a certain extent. From a welfare perspective, we therefore face the risk that even with ex-ante contracting the investing firm will choose not to grant market access and, consequently, foreclosure will result.

example, the retail prices of both firms would rise if a simple linear tariff w was increased (anticompetitive), while at the same time the investment incentives of the access-granting firm would increase (investment enhancing).

While access regulation is a standard policy instrument, we note that also the type of contract that is encouraged or discouraged is relevant: It is possible to influence investment incentives as well as retail prices by either encouraging or discouraging ex-ante (co-investment) contracts. On the one hand, as was previously shown, the signing of such contracts reduces the probability of duplicating investments, and, therefore, intense price competition. On the other hand, the probability that at least one of the firms invests increases.

Three welfare effects have to be taken into consideration, when assessing the impact of regulatory measures:

- the investment decision (and, thus, the quality of products offered on the market) and their impact on costs and consumer valuations,
- the allocation in the competitive segment (and, therefore, "transportation costs" in the model), and
- the deadweight loss in the monopoly segment (if $m_i(p_i)$ is decreasing in p_i—i.e., industry demand depends on price).

Access at Marginal Costs The regulator can decide whether firm 1 provides network access at marginal costs. If such a regulation is anticipated by the firms, at most one firm will invest in the new technology, thus excluding duplication of investment. As firm 1 has to cover the fixed costs itself, it will only invest if $I \leq \pi^*(1,1)$. As $\pi^*(1,0) > \pi^*(1,1)$, investments are less frequent than in a market without network access.

With price-independent industry demand neither of the firms benefits from the investment and, for every $I > 0$, none of the firms is willing to invest. We are, therefore, in the paradoxical situation that each firm is better off if the regulator announces a "tough" regulation scheme. As this deters firms from investing, profits of $\pi^*(0,0)$ arise. Without access regulation and under the assumption of sufficiently low investment costs, both firms would invest. Each firm then would make a profit of $\pi^*(1,1) - I$. As $\pi^*(1,1) = \pi^*(0,0)$ under price-independent industry demand, firms are in fact better off under the regulated regime.

Fixed-Cost Redistribution If investments costs are redistributed via a fixed payment, the above insight is still valid since higher investments lead to neither higher price-costs differences nor increased sales. In case of price-elastic demand, however, cost sharing increases investment incentives significantly. Such a rule could be a function of equilibrium sales q_1^* and q_2^*. Suppose that firm 1 had invested. Firm 2 may then have to make the fixed payment $(q_2^*/Q^*)I$ to firm 1 in order to receive network access at the marginal costs $k_1 = k^N$. With such an access rule, both firms are indifferent as to which one of them will actually make the investment (presuming that the required investment cost is the same for both of them). Of course, this cost-sharing rule does not typically lead to the first-best-efficient investment since firms are not able to extract the full additional rents resulting from the investment.

Access subject to a Fixed Cost Surcharge One can, in addition, determine a surcharge so that the access-seeking firm covers a part of the fixed costs that is exactly proportional to the number of times it accesses the network—i.e., one can determine a parameter w that satisfies $(w - k^N)q_2^* = (q_2^*/Q^*)I$. This is equivalent to writing $w = k^N + I/Q^*$. In this case, the price is clearly above marginal costs. Thus, the investing firm accrues higher profits than in the case of marginal cost based access, due to a direct and an indirect effect. The direct effect comes from profits arising in the access business, where $w > k^N$. The indirect effect of this higher access charge is a reduction in the intensity of competition in the retail sector. The reduction of competition is to the detriment of consumers, provided that the higher charge does not raise investment incentives sufficiently.

In our model, if both firms have the same efficiency in investing, the market outcome is not affected by the identity of the firm that invests. If there are differences in investment efficiency, the more efficient firm has a higher incentive to invest. As an example, consider the government undertaking an access regulation. If the government auctions a license to upgrade a network, the more efficient firm will acquire this license.

Access subject to a Variable Cost Surcharge The previously discussed surcharge had the property that investment costs are proportionally borne among firms in equilibrium. This essentially requires to "predict" the equilibrium outcome accurately. The regulator can, instead, choose an access surcharge that is determined ex-post and that distributes costs according to the realized market shares. Hence, to satisfy $(w-k^N)q_2 = (q_2/Q)I$ it holds ex-post that $w = k^N + I/Q$. If industry demand is price-independent, we observe that the access charge is constant.

On the contrary, if industry demand is price-dependent, firm 1 has now an incentive to reduce the number of own subscribers q_1 so as to reduce its share of the charges (cost sharing) w. Reversely, firm 2 has an incentive to increase its number of subscribers because this determines the reduction of the access surcharge. Regulation of this type secures a higher number of consumers for the access-seeking firm in equilibrium relative to the case of a fixed cost surcharge. Thus, by imposing a variable cost surcharge, regulation leads to a larger market share for the access-seeking firm. The effects on consumer welfare CS and aggregate welfare W depend on the specific assumptions of the model and, therefore, do not yield robust predictions.

Linear Access Markups If industry demand is price-independent, profits of the investing firm are increasing in w, while profits of the access-seeking firm are independent of w. Therefore, the higher the level of w, the more likely is the investment. Duplication of investments does not occur at all. If industry demand is price-dependent, returns of the investing firm are still increasing in w, but profits of the access-seeking firm decrease in w. A higher access surcharge leads to a reduction in the number of subscribers that the non-investing firm has in its hinterland. Since accessing the market through a competitor is costly, the access-seeking firm might find it, instead, more profitable to undertake an investment on its own. Hence, a higher access markup increases its investment incentives and, thus, the likelihood that network duplication will take place. However, if the corresponding equilibrium profits, denoted by $\pi^*(1, 0; w)$, do not cover the investment costs, regulators must subsidize the investment in the NGA network such that the subsidy covers $\pi^*(1, 0; w) - \pi^*(0, 0)$ minus the investment costs; otherwise, no investment will take place.

8 Concluding Remarks

In this paper we have analyzed the interplay of ex-ante and ex-post access contracts as well as access regulation with competition and investment incentives. Within a standard duopoly model, we have shown that ex-post access contracts lead less often to a duplication of investments, but to a wider roll-out compared to a market in which such contracts cannot be offered. In comparison to such ex-post contracts, ex-ante contracts lead to an even wider roll-out, but to a less frequent duplication of investments. However, ex-ante contracts in particular, but also ex-post contracts, can be used to dampen competition.

In the present work, we have generally taken the perspective that network operators are ex-ante symmetric. In further work, we focus instead on asymmetries between network operators, in particular in terms of the size of their "legacy network" (see Inderst and Peitz, 2011a). In the present work, we have also abstracted much from uncertainty, so as to streamline the exposition. Uncertainty is at the focus of Inderst and Peitz (2011b), where we explore the impact of regulation when there is large uncertainty about the market potential from new investments.

Appendix 1: Supplementary material on competition and equilibrium

When taking the first-order conditions, we obtain firm 1's best-response function:

$$p_1 = \tau \widehat{m}_1 + \frac{1}{2}k_1 + \tau\frac{1}{2} + \frac{1}{2}(u_1 - u_2) + \frac{1}{2}p_2.$$

Correspondingly, for firm 2:

$$p_2 = \tau \widehat{m}_2 + \frac{1}{2}k_2 + \tau\frac{1}{2} + \frac{1}{2}(u_2 - u_1) + \frac{1}{2}p_1.$$

As is well known in this type of models, the best-response function is increasing in the competitor's price. Thus, prices are strategic complements. The Nash equilibrium constitutes the intersection point of the best-response functions. Equilibrium prices are:

$$\begin{aligned} p_1^* &= \frac{2}{3}k_1 + \frac{1}{3}k_2 + \tau\frac{4\widehat{m}_1}{3} + \tau\frac{2\widehat{m}_2}{3} + \tau + \frac{1}{3}(u_1 - u_2), \\ p_2^* &= \frac{2}{3}k_2 + \frac{1}{3}k_1 + \tau\frac{4\widehat{m}_2}{3} + \tau\frac{2\widehat{m}_1}{3} + \tau + \frac{1}{3}(u_2 - u_1). \end{aligned}$$

The equilibrium price difference is:

$$p_2^* - p_1^* = \frac{2}{3}(u_2 - u_1) + \frac{1}{3}(k_2 - k_1) + \tau\frac{2}{3}(\widehat{m}_2 - \widehat{m}_1).$$

This price difference is, ceteris paribus, higher (1) the larger the utility difference of the two products, $u_2 - u_1$, (2) the greater the difference in costs, $k_2 - k_1$, and (3) the larger the difference in the size of each firm's hinterland, $\widehat{m}_2 - \widehat{m}_1$ (i.e., the captive consumers).

Equilibrium market shares in the competitive segment can be computed as

$$\widehat{x}^* = \frac{1}{2} - \frac{1}{6\tau}(u_2 - u_1) + \frac{1}{6\tau}(k_2 - k_1) + \frac{1}{3}(\widehat{m}_2 - \widehat{m}_1).$$

Equilibrium profits are

$$\begin{aligned} \pi_1^* &= \left(-\frac{dq_1}{dp_1}\right)(p_1^* - k_1)^2 = M\frac{1}{2\tau}(p_1^* - k_1)^2, \\ \pi_1^* &= \left(-\frac{dq_2}{dp_2}\right)(p_2^* - k_2)^2 = M\frac{1}{2\tau}(p_2^* - k_2)^2. \end{aligned}$$

Substituting for the values of equilibrium prices, we obtain the expressions for equilibrium profits reported in the main text.

Social welfare measured as total surplus (gross of investment costs) is given by

$$W = M\left[(\widehat{x} + \widehat{m}_1)(u_1 - k_1) + (1 - \widehat{x} + \widehat{m}_2)(u_2 - k_2) - T(\widehat{x})\right],$$

in which transportation costs $T(\widehat{x})$ are defined as

$$\begin{aligned} T(\widehat{x}) &= \int_0^{\widehat{x}} \tau x dx + \int_{\widehat{x}}^1 \tau(1-x)dx \\ &= \frac{\tau\widehat{x}^2}{2} + \frac{\tau(1-\widehat{x})^2}{2} = \frac{\tau}{2}(1 + 2\widehat{x}^2 - 2\widehat{x}). \end{aligned}$$

Transportation costs are minimized when the indifferent consumer $\widehat{x}$ is located at point 1/2. Welfare is maximized when

$$\frac{dW}{d\widehat{x}} = (u_1 - k_1) - (u_2 - k_2) - \tau(2\widehat{x} - 1) = 0.$$

Hence, the efficient allocation is determined by

$$\begin{aligned} \widehat{x}^W &= \frac{1}{2} + \frac{(u_1 - k_1) - (u_2 - k_2)}{2\tau} \\ &= \frac{1}{2} - \frac{u_2 - u_1}{2\tau} + \frac{k_2 - k_1}{2\tau}. \end{aligned}$$

We can compare this allocation with the equilibrium allocation, denoted by $\widehat{x}^*$. In the case of perfect symmetry ($u_1 = u_2$, $k_1 = k_2$, $m_1 = m_2$), the equilibrium allocation is efficient. However, as is well known, asymmetries can lead to inefficiency. This is due to the fact that when a firm has a larger market share, a marginal price decrease is "more expensive", since it must be applied to a larger volume, leading to a larger negative effect on profits. For instance, in equilibrium, a more efficient firm will exhibit a higher margin and will possess a larger, though not sufficiently large, market share. Alternatively, when $u_1 - k_1 = u_2 - k_2$, the firm with the largest hinterland has an inefficiently low share of the competitive segment. The reason is, again, that a firm with a larger hinterland acts less aggressively in the competitive segment because, without differentiating the price over the various segments, a price reduction is applied to a larger volume ($M\widehat{x}^* + m_i$) and is, ultimately, more expensive.

Appendix 2: Supplementary material on price-dependent industry demand.

With symmetric hinterlands, $\mu \equiv \mu_1 = \mu_2$, $a \equiv a_1 = a_2$, $b \equiv b_1 = b_2$, we can write firm i's demand as a linear function of both prices

$$q_i = M(\alpha_i - \beta p_i + \gamma p_j),$$

in which

$$\begin{aligned}
\alpha_i &= \frac{1}{2} + \mu a + \left(\frac{1}{2\tau} + \mu\right) u_i - \frac{1}{2\tau} u_j, \ j \neq i, \\
\beta &= \frac{1}{2\tau} + \mu b, \\
\gamma &= \frac{1}{2\tau}.
\end{aligned}$$

The first-order conditions of the profit-maximization problem $\max_{p_i}(p_i - k_i)q_i$ lead to:

$$\begin{aligned}
p_1 &= \frac{\alpha_1 + \beta k_1 + p_2\gamma}{2\beta}, \\
p_2 &= \frac{\alpha_2 + \beta k_2 + p_1\gamma}{2\beta}.
\end{aligned}$$

In equilibrium, firm 1's price is determined by

$$p_1^*(4\beta^2 - \gamma^2) = 2\beta(\alpha_1 + \beta k_1) + (\gamma\alpha_2 + \beta k_2).$$

Therefore, the equilibrium price of firm 1 is:

$$p_1^* = \frac{2\beta(\alpha_1 + \beta k_1) + \gamma(\alpha_2 + \beta k_2)}{4\beta^2 - \gamma^2}.$$

Similarly, for firm 2.

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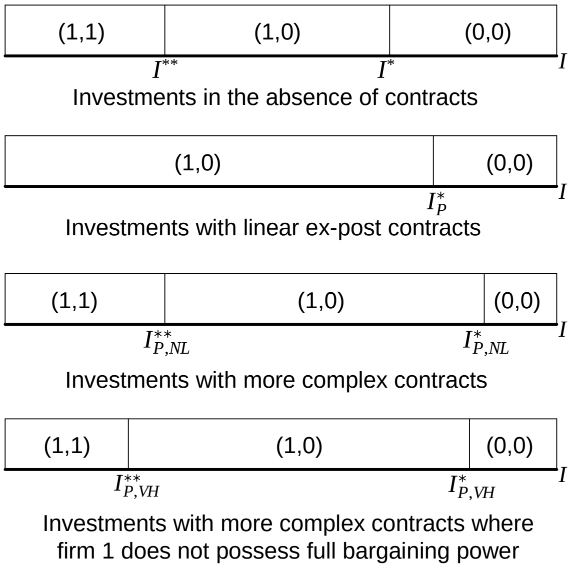

Figure 1: Investments and ex-post contracting

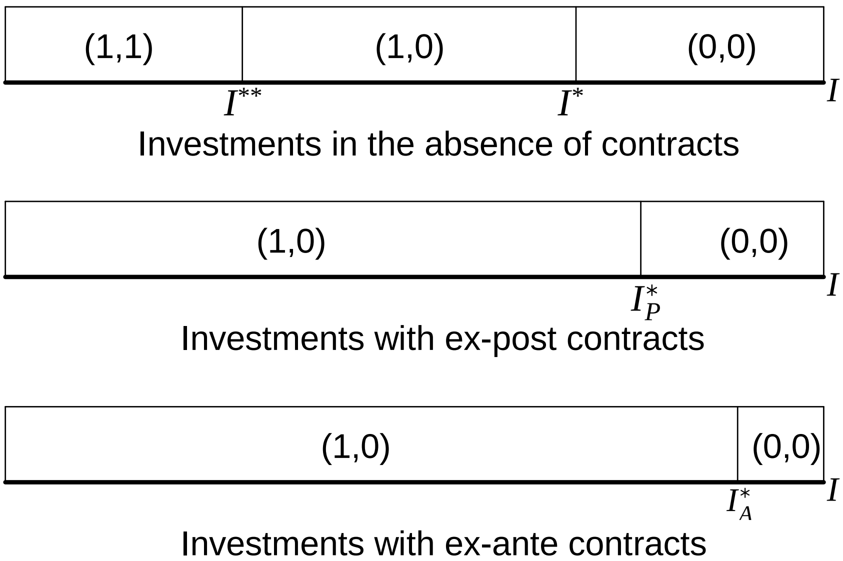

Figure 2: Investments and contracting