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Co-Investments and Tacit Collusion in Regulated Network Industries: Experimental Evidence*

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Abstract

With the use of a laboratory experiment, we show the effects of co-investments on coverage, competition and price collusion in regulated network industries. On the one hand, co-investments turn out not to be a significant driver of new infrastructure investments beyond the level achieved by access regulation and they seem to facilitate tacit price collusion. On the other hand, co-investments economize on infrastructure investment costs and necessitate communication, which partially offset the aforementioned effects. In fact, communication between the firms on their future coverage, especially outside co-investments, seems to have a positive effect on investments. However, the surprising message of the experiment is that tacit collusion happens under co-investment although there is no reason to believe that it should and although we made almost every effort to prevent it. Our results indicate that regulators should evaluate co-investments with scrutiny as there are definite drawbacks that must be considered.

Keywords: experimental economics, network industries, co-investment, collusion, regulation

JEL Classification: C92; L13; L50; L97

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1 Introduction

The roll out of new network infrastructure (e.g., in the context of fiber-to-the-home) is very costly, especially if tied to the political goal of a widespread availability of this infrastructure. Such investments are perceived as particularly risky, because their large size is coupled with sunkness, with the fear of duplication and with uncertainty of future demand. Co-investment by several potential investors can combine their financial resources and virtually eliminate the risk of duplication. Several regulatory authorities throughout the world have therefore allowed firms to co-invest in new network infrastructure. Examples with respect to the telecommunications industry are Switzerland, Germany, France and Italy (see, e.g., Bourreau et al., 2010). This has been done in the belief that the cost savings that can be achieved by co-investments will spur network coverage and may additionally reduce retail prices. In this vein, co-investments are considered to have an unambiguously positive effect on consumers' surplus.

In this paper we scrutinize the regulatory case in favor of co-investments. In particular, we investigate whether co-investments may facilitate tacit price collusion. If so, this would clearly mitigate the positive prospects of co-investments on welfare. In particular, our main research questions are: (i) Do co-investments indeed yield a higher network coverage than conventional cost-based access regulation? (ii) Do co-investments facilitate tacit collusion on prices? (iii) What is the overall effect of co-investments on consumers' welfare?

These questions are addressed with the tool of economic laboratory experiments. Similar to Normann and Ricciuti (2009), we believe that this new approach to regulatory economics with respect to network industries can be very useful for several reasons:

First, economic laboratory experiments have already proven to be a good testbed for regulatory institutions (e.g., for the design of frequency auctions). In this vein theoretical flaws in the design of a regulatory institution can effectively be discovered. If a regulatory institution fails in the laboratory, there is little reason to believe that it will perform in the field (Plott, 1987). Second, almost by definition, empirical data on the effectiveness of a new regulatory option, like co-investments, is not available. At best, empirical data is available for other countries or from other domains, but for the application in question, empirical data becomes available only after a new regulatory framework has been implemented. However, if the new framework contains flaws, or does not perform as planned, it is already too late and a change of regulatory regimes can be very costly. To the extent available, empirical data from comparable scenarios can be used, next to experimental data, in order to check the robustness of the derived results. Third, even if empirical data was available, this data lacks control and pertinent costs are often not known. Therefore, it is difficult, if not impossible to reveal causal relationships between unobservable, but important latent variables. In the present context, for example, it would be virtually impossible to prove empirically that co-investments have led to tacit collusion, because the actual costs and the competitive price level of a new service are not known.

In order to study the impact of co-investment on the extent of coverage and tacit collusion in the laboratory, we first develop a simple game that captures the essential features of dynamic network competition under access regulation. In the first stage of the game, the firms determine the coverage of their networks, i.e., the size of the relevant market. Depending on the treatment, investments in network infrastructure can be made only independently or cooperatively and independently. In the second stage, firms compete for subscriptions of those households that have been connected to the network. According to the current regulatory practice for broadband, firms can also acquire access to those households that are only connected to the rival network at the regulated access charge. Thus, the firms compete for subscriptions by all covered households in the joint network. In the laboratory experiment, we find that co-investment occurs in about 50% of the cases when it was feasible. However, the possibility to co-invest does not increase the joint network coverage beyond the level that is achieved absent the possibility to co-invest. In reverse, we find that those firms that have co-invested in the first stage of the game, tacitly collude more in setting their retail prices in the second stage. The surprising message of the experiment is that tacit collusion happens under co-investment although there is no reason to believe that it should and although we made almost every effort to prevent it. Therefore, as co-investments do not seem to lead to more coverage, their effect on consumers' surplus depends on the level of retail prices. It can be shown that despite tacit collusion, retail prices under co-investments are comparable to those under independent investments, because co-investments also economize on infrastructure investment costs. The overall regulatory assessment of co-investments should thus be based on the expectation which effect prevails: the cost-reducing effect or tacit collusion. In any case, our results indicate that the prospects of co-investments on consumers' welfare may not be as positive as commonly expected.

The relationship between regulation and investment has attracted a large literature, which is reviewed in general by Guthrie (2006) and with respect to broadband infrastructure by Cambini and Jiang (2009). More specifically, the few theoretical contributions with respect to co-investments in broadband markets are reviewed by Bourreau et al. (2012, p. 404-405). In particular, Nitsche and Wiethaus (2010, 2011) compare co-investments (which they call 'risk-sharing') with long-run incremental cost pricing, fully distributed cost pricing and regulatory holidays. They find that co-investment regulation yields the highest consumers' surplus because it provides a balance between investment incentives and competitive intensity. Similar results are obtained by Cambini and Silvestri (2012) who also show that risk-sharing emerges as the most favorable regime with respect to consumers' surplus for a large range of parameters. However, both papers do not take the possibility of tacit collusion into account. Moreover, Hoernig et al. (2012) combine an engineering cost model with a differentiated multi-player oligopoly model to investigate the business case of co-investments in fiber roll-out and their relationship to geographical markets and access regulation. From a methodological point of view, the paper that is most related to ours is Henze et al. (2012). The paper has a very different focus, however. With an economic laboratory experiment, the authors compare the effects of price caps and regulatory holidays on network infrastructure expansion in the context of electricity markets. Tacit collusion is not considered. More generally, the circumstances under which tacit collusion in oligopolies may arise have been extensively studied in experimental economics. Engel (2007) provides a comprehensive survey and meta-analysis. For example, co-investments could be interpreted as an explicit capacity coordination mechanism, which was found to facilitate tacit collusion in the presence of demand shocks by Hampton and Sherstyuk (2012).[1] This paper, however, appears to be the first experimental comparative study

[1] Also Cason and Mason (1999) and Rojas (2012) find that the level of tacit collusion is affected by demand uncertainty. Firms face no demand uncertainty in our study, however.

that systematically investigates the effect of co-investments on network coverage and tacit collusion in regulated network industries.

The remainder of this article is structured as follows. The next section presents the network competition game, which builds the theoretical foundation for the subsequent experimental analysis. Section 3 describes the design, Section 4 the procedure and Section 5 the results of the experiment. Finally, we conclude by summarizing and discussing the implications of our findings in Section 6.

2 The Network Competition Game

Our experiments are based on the following "network competition game", which captures the essential features of competition between two firms ($i, j \in \{1, 2\}$) in a network industry, e.g., the telecommunications industry. It is assumed that firms compete in offering a new service (e.g., fiber-to-the-home) to the same end customers (households). However, before firms can do so, they first have to invest in new network infrastructure (greenfield approach). More precisely, households are located in three distinct regional areas:

- Area I is a metropolitan area with n_I households.
- Area II is an urban area with $n_{II} < n_I$ households.
- Area III is a rural area with $n_{III} < n_{II}$ households.

Let the corresponding infrastructure investment costs for *each* area be k. Notice that by the economics of density it is therefore more costly to connect a rural household to the network infrastructure than it is to connect a household in a more densely populated area. As will be seen later, firms will evaluate the average connection costs per household, i.e., $^{n}/_{k}$. Therefore, the normalization that the investment costs in each area are k is without loss of generality. For the case that a firm builds infrastructure in a given area we assume for simplicity that all households in that area are being connected to the network, although not all of them necessarily subscribe to that network. This characterization roughly holds true for fiber-to-the-home access networks (see Hoernig et al., 2012). The set of areas in which firm i owns infrastructure is called i's coverage and denoted by N_i. The total area covered by the industry is therefore $\overline{N} = N_1 \cup N_2$. Similarly, the number of households that are connected (but not necessarily subscribers) to i's network are called i's customer base and denoted by $n_i = \sum_{\zeta \in N_i} n_\zeta$. The size of the relevant market, i.e., the total number of households that are located in $\overline{N}$, is $\overline{n}$. Access regulation is in effect whenever one firm monopolizes the network infrastructure in an area. Hence, firm i has to grant firm j access in areas $N_i \backslash N_j$, such that firm j can also provide its service to the $\overline{n} - n_j$ households that it does not cover with own infrastructure. According to the current regulatory practice in the telecommunications industry, the access charge which firm j has to pay to firm i for using its infrastructure in those areas is regulated and calculated according to the long-run incremental costs (LRIC), which are described in more detail later. The marginal costs for serving households over own infrastructure are w.l.o.g. set to zero.

2.1 Structure, Treatments and Payoffs

The game consists of two subsequent phases: First, the firms must decide on their coverage area (investment phase). During this phase co-investment may be possible or not, and communication with the other firm (cheap talk) about the investment decisions may or may not be allowed. Second, firms compete in prices when offering their new service to covered households (retail phase). The game proceeds in discrete time steps, denoted by t. The details and timing of each phase are described in the following.

2.1.1 Investment Phase (t=0)

In this phase the two firms must decide on their coverage N, i.e., in which areas they would like to invest. Three different treatment conditions are considered:

No co-investment (NoCo) In this treatment the firms decide sequentially on their coverage area and each firm has to bear the full infrastructure investment costs on its own: In order to provide a first mover advantage to the incumbent, say firm 1, this firm may choose its coverage first. Subsequently and observing the choice of firm 1, firm 2 can choose its coverage. In particular, this means that network infrastructure will be duplicated in those areas that are covered by both firms. Firms are not allowed to communicate prior to investing in this treatment.

Co-investment (Co) This treatment is identical to the no co-investment treatment with the exception that a co-investment phase is added at the beginning. This means that the two firms can make a binding contract on which areas they will cover, prior to deciding on their infrastructure investments independently. During the co-investment phase communication between the two firms is allowed in order to facilitate coordination on common coverage areas. However, communication about prices is strictly prohibited.[2] In this way a so-called Chinese wall approach is implemented, which mimics the corresponding regulatory remedy that has been suggested in the context of co-investments. While it is obviously infeasible that firms engage in co-investments without prior communication of the investment departments of the respective firms, the Chinese wall regulation demands that at least the retail departments are not allowed to communicate. In this vein, the possibility for price collusion is deemed to be limited. As with exclusively owned infrastructure, firms bear no marginal costs on common infrastructure. However, in those areas that the firms agree to cover together *ex-ante*, each firm has to bear only a fraction of the independent investment costs, i.e., $\alpha_i k$, with $0 < \alpha_i < 1$.[3]

No co-investment with chat (NoCoC) In this treatment firms can communicate prior to their investment decisions although co-investments are not allowed. Otherwise this treatment is identical to the no co-investment treatment. The same Chinese walls restrictions on price communication as in the co-investment treatment apply. Hence, this treatment serves as a robustness check with respect to the impact of communication on market outcome.

[2] Communication was text-based and monitored in real time during the experiment to ensure compliance. Moreover, a perfect stranger matching procedure was adopted which implied that participants were also not allowed to reveal their identity and that they knew the probability of being re-matched with the same participant was exactly zero.

[3] By contrast, if both firms decide to cover the same area independently, then no co-investment takes place and each firm has to bear the full infrastructure investment costs.

Investment costs Consequently, the total (sunk) infrastructure investment costs of firm i are

$$K_i = k \cdot (\alpha_i |N_i \cap N_j| + |N_i \backslash N_j|)\,, \tag{1}$$

where $\alpha_i < 1$ in Co and $\alpha_i = 1$ otherwise.

2.1.2 Retail Phase (t=1,...,T)

Subsequent to the investment phase, at time $t = 1, \dots, T$, the two firms compete in the retail market for households/customers.

Demand More specifically, we assume that firms offer a homogeneous service and compete in prices (Bertrand competition). This means that in each period $t = 1, \dots, T$, each firm i simultaneously and independently specifies a single retail price $p_{i,t}$ for its service. There is a regulatory requirement for the firms to provide their service in the industry's whole coverage area or not at all (must serve obligation) and to set a uniform price for all households across geographic areas. This requirement also holds for the non-investing firm. In reality must serve obligations are only imposed on incumbents. Requiring them for non-investing firms serves as a simplification in order to reduce complexity for the participants in the experiments. For broadband, uniform retail pricing is imposed in no place that we know of. In practice firms often use it voluntarily, though. The alternative to uniform pricing would have been that firms can set an individual price in each geographic region. This would make it much more difficult trying to assess collusion and would most likely result in more 'noise' in the experiment rather than strategic and deliberate action. Likewise, households have a uniform willingness to pay of v for the service of either firm. They will buy exactly one unit of the service exclusively from the firm that has the lower price, as long as that price does not exceed v.[4] One can think of the service as subscription with flat rate usage.

In case the retail prices of the two firms are equal, the incumbent's service is assumed to be more attractive to the households. In this case households will choose the incumbent's service with probability $0.5 \leq \delta_1 < 1$ and the entrant's service with probability $\delta_2 = 1 - \delta_1$. Remember that each firm must seek access from the other firm in those areas that are covered by its competitor but not by itself. This, in combination with the must serve obligation, means that the firm that has the lower price will receive the full market demand $\overline{n}$, whereas the firm with the higher price receives no direct demand at all. In other words the demand function is:

$$D_i(p_i, p_j) = \begin{cases} \overline{n} & \text{if } p_i < p_j \ \& \ p_i \leq v \\ \delta_i \overline{n} & \text{if } p_i = p_j \ \& \ p_i \leq v \\ 0 & \text{if } p_i > \min\{p_j, v\} \end{cases} \tag{2}$$

We assume Bertrand competition in the retail phase of our model, because it is well suited to study the extent of tacit collusion in an experimental setting for several reasons. First, Bertrand competition is easy to explain and very intuitive in contrast to,

[4]The must serve obligation refers only to those households that live in an area that has been covered/connected in the first stage of the game. While the must serve assumption most probably is not uncritical with respect to the market dynamics, any firm has the option to set a price above the consumers' willingness to pay of v, which effectively means that it will never receive any demand and thus it does not serve the market. The only caveat is that, because differentiated prices are not possible, this means that this firm does not serve any region. In other words, a firm is not able to pick only certain (covered) markets in which it competes.

e.g., quantity setting. Hence, we can be sure that subjects understand the consequences of their action and that the level of prices is due to strategic reasoning and not to randomness, as might be suspected for more complicated models of competition. Second, there exists a clear theoretical prediction for the equilibrium price level under Bertrand competition, also for the case of repeated interaction. Third, with price competition the extent of tacit collusion can be readily assessed through established metrics, such as the Lerner index.

Costs As noted above, without further loss of generality we assume that firms have no marginal costs of providing the service over their *own* infrastructure. This assumption is also in line with the theoretical model of Nitsche and Wiethaus (2011). However, if the service is provided over foreign infrastructure, firms have to bear marginal costs in the form of the regulated access charge a, which is paid per period and household. In line with the current regulatory practice a is computed according to the long-run incremental costs (LRIC), which depend on the firms' investment decisions. More specifically, the access charge that firm i would have to pay $j \neq i$ (per period and household that it serves over j's infrastructure) is:

$$a_i = \begin{cases} 0 & \text{if } K_j = 0 \\ \gamma \frac{K_j}{T \cdot n_j} = \text{LRIC}_j & \text{if } K_j > 0. \end{cases} \tag{3}$$

The access charge is therefore equal to the the total investment of the firm providing access divided by number of households connected to that network times the number of periods.[5] In addition, the LRIC include a return on investment of $\gamma \geq 1$. In other words, γ is the assumed interest rate on capital. Note that we assume throughout that profits and costs are not discounted. This is a natural assumption in the laboratory environment where all profits accrue in experimental money that cannot be put to alternative use during the experiment, and that is paid in full at the end of the experimental session. Consequently, firm i's average marginal costs are

$$c_i = \frac{\overline{n} - n_i}{\overline{n}} a_i \tag{4}$$

Profits In each period $t > 0$, firm i's operative profit, $\Pi_{i,t}$ is thus given by the sum of its retail profit, $R_{i,t} = D_{i,t}(p_{i,t} - c_i)$, and its wholesale profit from the provision of access to its competitor, $W_{i,t} = D_{j,t}\, c_j$, i.e.,

$$\Pi_{i,t} = R_{i,t} + W_{i,t} = D_{i,t}(p_{i,t} - c_i) + D_{j,t}\, c_j. \tag{5}$$

Thus, at the end of period T, firm i receives the sum of its profits from periods $t = 1 \ldots T$, reduced by the infrastructure investment costs from period $t = 0$. The final profit of firm i is therefore:

$$\Pi_i = \sum_{t=1}^{T} \Pi_{i,t} - K_i \tag{6}$$

[5]Notice that this straight forward calculation of the LRIC is only feasible under the must serve obligation. Otherwise, the notion of LRIC implies that the regulator would have to know ex ante the actual number of subscriptions that will be sold by either firm ex post.

2.2 Theoretical Prediction

We now investigate the equilibrium outcome of the above model with respect to firms' (i) coverage and (ii) prices under the three different regulatory scenarios.

Retail Equilibrium First, consider the strategic interaction in the retail phase, given the firms' decisions from the investment phase. In fact, because the firms' investments in network infrastructure are sunk, these costs are relevant only insofar in the retail phase as they determine the access charge that firms have to pay each other. The access charge, however, may lead to positive marginal costs for the access seeker. In particular, we can distinguish three cases: First, if both firms have invested symmetrically, i.e., $N_1 = N_2$, then access to the other firm's network is not necessary and thus the firms' average marginal costs are $c_i = 0, i = 1, 2$. Second, if $N_i \subset N_j$, then only firm i seeks access from j, such that $c_i > 0, c_j = 0, i \neq j$. Third, if $N_i \subset \overline{N}, i = 1, 2$, then both firms seek access from each other, such that $c_i > 0, i = 1, 2$. A firm's average marginal costs are important for the price level in the retail phase because they determine a lower bound on prices. In particular, let p_t denote the market price in period t. Then the unique price Nash equilibrium of any Bertrand subgame in the retail phase $t = 1, \ldots, T$ is given by

$$p_t^* = \lceil c_1 + c_2 \rceil, \tag{7}$$

where $\lceil \cdot \rceil$ returns the smallest feasible price level that is larger than its argument. In other words, the equilibrium price is at most one price increment, denoted by ϵ, above the sum of the firms' average marginal costs. The reason why firms consider the sum of their average marginal costs instead of the maximum average marginal cost (as would be the case in a standard Bertrand game) is the following: A firm's average marginal costs represent the access charge (wholesale profit) that the competitor receives on average for each household that is served by that firm. Thus, the other firm's marginal costs are one's own opportunity costs and therefore the sum of the firms' average marginal costs constitutes a lower bound on prices. This is in line with the literature on the costs of inputs sold to bottleneck competitors (see DeGraba, 2003, where homogeneous goods imply a diversion ratio of one). In our case it is as if the access provider were vertically separated into an upstream network owner and a downstream retail company that has to buy access from its own network company just like a competitor who does not own an upstream network. At the same time, by the usual logic of Bertrand competition, the equilibrium price cannot exceed the sum of the firms' average marginal costs plus one price increment. Therefore, in equilibrium both firms will price their retail product at $p_{i,t} = p_t^* \leq v$ and receive a demand of $D_{i,t}^* = \overline{n}\delta_i$. Hence, a firm's equilibrium profit is

$$\Pi_{i,t}^* = \overline{n}\delta_i(p_t^* - c_i - c_j) + \overline{n}\, c_j. \tag{8}$$

More formally, it can be shown that (7) constitutes the unique price equilibrium, because no firm wants to unilaterally deviate from this price:

i) No firm would like to raise its price above p_t^*, say to $p_t^* + \epsilon$: In this case it would lose all demand for its retail product and receive payoffs from wholesale access only, such that its profit is

$$\Pi_{i,t}^{+\epsilon} = \overline{n}c_j.$$

It is easy to see that $\Pi^*_{i,t} > \Pi^{+\epsilon}_{i,t} \Leftrightarrow p^*_t > c_i + c_j$, which is satisfied by (7).

ii) No firm wants to lower its price below p^*_t, say to $p^*_t - \epsilon$: In this case it would receive the full market demand ($\overline{n}$), but at the same time lose all profits from wholesale, i.e.,

$$\Pi^{-\epsilon}_{i,t} = \overline{n}(p^*_t - \epsilon - c_i).$$

It follows that $\Pi^*_{i,t} > \Pi^{-\epsilon}_{i,t} \Leftrightarrow p^*_t < c_i + c_j + {}^{\epsilon}/_{\delta_i}$, which is also satisfied by (7) since $0 < \delta_i < 1$.

Further, under reasonable assumptions about the equilibrium concept of the finitely repeated Bertrand game, the above unique equilibrium of the Bertrand subgame is also the unique equilibrium of the whole, repeated Bertrand game, i.e., $p^* = (p^*_1, \ldots, p^*_t, \ldots, p^*_T)$. For example, Farrell and Maskin (1989) show that p^* is the unique weakly renegotiation proof (WRP) equilibrium of the repeated Bertrand game. It is also the unique subgame perfect equilibrium (Selten, 1975).[6]

Investment Equilibrium In the investment equilibrium firms anticipate that the equilibrium retail price is $p^*_t = c_1 + c_2 + \xi$, where ξ denotes the mark up on costs that is due to the price increment (i.e., $\xi = \lceil c_1 + c_2 \rceil - (c_1 + c_2)$). Consequently, firm i will make retail profits of

$$R^*_i = \overline{n}\delta_i T(c_j + \xi) \tag{9}$$

[6]Other, non-subgame-perfect Nash-equilibria are possible of course, e.g., through grim trigger strategies.

and additionally, if $N_i \supset N_j, j \neq i$, wholesale profits of

$$W_i^* = \overline{n}(1-\delta_i)Tc_j \tag{10}$$

In sum, substituting the equilibrium values from (9) and (10) in (6) while regarding equations (3) (4) and (5), the equilibrium profit is

$$\Pi_i^* = \begin{cases} \overline{n}\delta_i T\xi & \text{,if } n_i = 0 \\ \left(\gamma\frac{\overline{n}-n_j}{n_i} - 1\right) K_i + \overline{n}\delta_i T\xi & \text{,otherwise.} \end{cases} \tag{11}$$

Notice that the first summand of the profit function (in case of positive investments), gives the expected *return on investment (ROI)*.

$$\text{ROI}_i := \begin{cases} 0 & \text{,if } n_i = 0 \\ \gamma\frac{\overline{n}-n_j}{n_i} - 1 & \text{,otherwise} \end{cases} \tag{12}$$

A firm's ROI hinges on the quotient $\frac{\overline{n}-n_j}{n_i}$ which can be interpreted as the firm's network monopoly share of the customer base. In other words, it measures the number of households that are not covered by the *other* firm $(\overline{n} - n_j)$ relative to the number of households that are covered by the *own* firm (n_i). Because $\overline{n} \leq n_1 + n_2$ it holds that $\frac{\overline{n}-n_j}{n_i} \leq 1$. Consequently, for $\gamma = 1$, a firm's ROI is at best zero. In other words, for $\gamma = 1$, the firms should realize that any duplication of infrastructure in the investment phase will inevitably lead to losses by the end of the retail phase if firms stick to

the equilibrium price path.[7] However, for $\gamma > 1$ a firm's ROI can be positive. More specifically, ROI is obviously maximized when $\overline{n} = n_1 + n_2$, i.e., when firms avoid any duplication of infrastructure. In this case, each firm's ROI is $\gamma - 1$.
Additionally, independent of γ and investments, firms can always make a small profit from the price increment related mark up on costs ($\overline{n}\, \delta_i T \xi$). However, this additional profit is generally negligible and goes to zero as $\epsilon \to 0$. Consequently, in the investment phase the ROI of both firms is maximized by investing such that $\overline{n} = n_1 + n_2$.

In this case, both firms receive the maximal ROI of $\gamma - 1$ on their invested capital K_i. Therefore, whenever $\gamma > 1$ the first mover in the investment phase (i.e., the incumbent firm 1) anticipates that the second mover (i.e., firm 2) will invest in all profitable areas that firm 1 has left uncovered. Consequently, firm 1 will invest maximally, leaving no profitable area uncovered. The profitable areas in which firm 1 will invest are derived as follows. First notice that the equilibrium price is

$$p_t^* = \frac{\overline{n} - n_1}{T\overline{n}n_2} K_2 \gamma + \frac{\overline{n} - n_2}{T\overline{n}n_1} K_1 \gamma + \xi.$$

Since the independent development of each area costs k, and $n_I > n_{II} > n_{III}$, the equilibrium price will increase as firms start to successively invest in less densely populated areas. Thus, none of the two firms will want to invest in an additional area if the equilibrium price exceeds the households' willingness to pay, i.e., $p_t^* > v$. Let us

[7] The mathematical model says that duplication of infrastructure is never profitable. Loosely speaking, the reason is that facilities-based Bertrand competition (where marginal costs for both firms are zero) will drive prices down to zero such that no investment cost can ever be recovered. Thus firms will refrain from duplication. This result is per se not related to the fact that firms must offer the same price to all connected households. Say firms duplicated in area I but not in area II and could demand differentiated prices, then price competition in area I would still drive prices down to zero and firms would therefore avoid any duplication.

denote the set of profitable areas by $\overline{N}^*$ and the corresponding market size by $\overline{n}^*$. Also notice that it is irrelevant for the equilibrium price how the coverage $\overline{N}^*$ is distributed among the two firms as long as $\overline{n}^* = n_1 + n_2$.

The Nash equilibrium of the independent investment phase, provided $\gamma > 1$ is therefore constituted by a situation in which firm 1 invests alone in all profitable areas $\overline{N}^*$ and firm 2 will not invest at all. To see this, consider the investment equilibrium candidate $N_1^* = \overline{N}^*$ and $N_2^* = \emptyset$. In this case, both firms make a positive equilibrium profit according to equation (11). Provided with the investment decision of firm 1, firm 2 has two alternative investment options:

i) Investing in an area in which firm 1 has already invested:

   In this case, infrastructure is duplicated but not expanded. This changes ROI_2 from zero to -1. In addition, firm 2 has to bear positive investment costs in this case. Thus, deviating by duplication of infrastructure is not profitable.

ii) Investing in an area in which firm 1 has not yet invested:

   As $N_1^* = \overline{N}^*$ any further expansion of the coverage area yields $p_t^* > v$. Consequently, firm 2 would make a loss when it sells at $p_t \leq v$.

Now let us consider if profitable deviations for firm 1 exist:

i) Investing in fewer areas than $\overline{N}^*$, say $\overline{N_1}^-$:

   In this case, firm 1 leaves a profitable area uncovered, which will subsequently be covered by firm 2. Thus $\overline{n}^*$ will not change, but instead of $\overline{n}^* = n_1^*$ it holds that $\overline{n}^* = n_1^- + n_2$. Because duplication of infrastructure is avoided, ROI_1 remains unchanged. However, since firm 1 has invested less capital K_i than before, it receives a smaller profit according to equation (11) and is thus worse off.

ii) Investing in more areas than $\overline{N}^*$:

Again, this would yield $p_t^* > v$, which would lead to losses and make firm 1 worse off.

Furthermore, it is easy to see that also any type of co-investment prior to the independent investments cannot be profitable. As with any investment, co-investments are sunk for each firm and in the absence of additional marginal costs (because no firm has to pay an access charge for using the common infrastructure) these investments, no matter how little they may be, deteriorate the ROI. In other words, co-investments forgo potential profits from wholesale access and will therefore be avoided in equilibrium. The equilibrium prediction is not biased in favor of co-investments because co-investments should not arise in equilibrium. However, it is also not biased against co-investments. In fact, the treatments were designed such that there should (theoretically) not be any differences between them; neither with respect to coverage in the investment phase, and because investments are sunk, nor with respect to prices in the retail phase. Consequently also producers' surplus, consumers' surplus and total welfare are expected to be identical equilibrium outcomes across treatments. In experimental economics, this is usually the favored approach. In this way any differences that are observed between the treatments relate directly to actual deviations from theory. However, if it had been our focus to show that co-investments do not stimulate investments, then we would get a stronger result if we could show that there are no differences in investment with and without co-investment despite the fact that co-investments were expected to perform better. We even implemented some "unrealistic" advantage for co-investments because we assumed that costs will be the same under co-investment as under non-duplicative individual investment. In contrast, in real world scenarios it is likely that co-investments will necessitate some additional investments which make them more costly than individual independent investments. It also has to be kept in mind that the theoretical model is only meant as a framework and playing-field for our experiment, from which additionally we can derive some theoretical predictions.

3 Experimental Design

Table 3 shows the parameter values of the network competition game that were adopted for the experiment. Under this specification, the unique equilibrium entails that firm 1 (the incumbent) builds up own network infrastructure in all three areas, whereas firm 2 (the entrant) does not invest at all. The sum of the firm's marginal (opportunity-) costs is 28.29 experimental currency units (ECU) and thus the resulting equilibrium price is 29 ECU. In equilibrium the incumbent and entrant make a profit of 2.175m ECU and 0.125m ECU, respectively. This holds under all treatment conditions. Notice that the total demand is shared 75/25 in favor of the incumbent at equal prices, and thus also in equilibrium. This has been done in order to create an asymmetry between the firms, which should hinder tacit collusion. This demand share is also reflected in the share of individual costs under co-investments. Here the incumbent (entrant) has to bear 75% (25%) of the total costs. Otherwise the entrant would be put at a disadvantage and possibly refrain from co-investments for this reason alone.

Parameter Description	Value
Number of households in each area:	$n_I = 40.000$
	$n_{II} = 20.000$
	$n_{III} = 10.000$
Development costs per area:	$k = 6.000.000$
Cost share (for co-investments):	$\alpha_i = \delta_i$
Demand share (at equal prices):	$\delta_1 = 0.75, \delta_2 = 0.25$
Consumers' willingness to pay:	$v = 50$
Interest rate:	$\gamma = 1.1$
Number of retail periods:	$T = 10$
Price increment:	$\epsilon = 1$
Budget:	$b = 18.000.000$
Exchange factor:	ECU/EUR = 1.000.000

Table 1: Parameter values used for the experiments

In the experiment, participants were endowed with an initial budget of 18m ECU in order to be able to cover the expenses of network infrastructure investments in all three areas. The remaining budget was added to a participant's profits in the network competition game and paid out in cash at the end of the experiment. Thereby, 1m ECU was converted to 1 EUR.

4 Experimental Procedure

All treatments were run in sessions with 6 participants. There were 4 sessions for each of the 3 treatment conditions, i.e., 72 participants in total. Each participant was exclusively assigned to one treatment condition (between subject design) and played 5 rounds of the network competition game with a different partner in each round. Thus, in the course of the five rounds every one of the six participants was matched to every other participant exactly once in random order and the possibility to be re-matched to the same partner was zero (perfect stranger matching). The participants knew that they would never play with the same firm twice and hence, this matching procedure should exacerbate tacit collusion. In each round the assignment of incumbent and entrant was randomly chosen, the previous account balance was cleared and participants were endowed with the initial budget anew. The earnings (firm profit plus remaining initial budget) of only one round were paid out at the end of the experiment in order to avoid budget effects and (together with the perfect stranger matching) to create independence between the rounds. The first round was declared as a practice round. Thus it was not relevant for the final pay off and is also not considered in the subsequent analysis. At the end of the experiment participants threw a four-sided dice in order to determine which of the remaining four rounds was paid out to them. Subjects' average monetary earning was 20.55 EUR.

The experiment was computerized and programmed in *z-Tree* (Fischbacher, 2007). The experiment was conducted at the Karlsruhe Institute of Technology in November 2011. Participants were recruited using the *ORSEE* software (Greiner, 2004). During the recruitment and execution of the experiment every effort was made to achieve a competent experimental outcome. First, all participants were students with a background in economics. Second, each participant had to pass a comprehension test before being eligible for participation. Third, during the experiment participants were equipped with a calculator and provided with information on LRICs as well as demand and profit forecasts, given their expectation of prices.[8]

[8]The instructions as well as screenshots are provided in the appendix.

5 Results

Table 2 summarizes the results with respect to coverage, prices and consumers' surplus across treatments.

Treatment	Variable	Obs.	Mean	Std. Dev.
Co	Coverage (areas)	48	2.33	0.83
	Coverage (HH)	48	59,375.00	17,061.37
	Avg. market price	47	32.42	10.18
	Lerner Index (MC)	47	0.57	0.41
	Lerner Index (AC)	94	0.38	0.32
	Consumers' surplus	48	10,574,583.33	6,431,523.42
NoCo	Coverage (areas)	48	2.13	0.94
	Coverage (HH)	48	53,750.00	21,100.07
	Avg. market price	45	31.85	10.60
	Lerner Index (MC)	45	0.25	0.22
	Lerner Index (AC)	90	0.21	0.24
	Consumers' surplus	48	9,949,583.33	6,613,235.59
NoCoC	Coverage (areas)	48	2.75	0.48
	Coverage (HH)	48	66,458.33	8,118.69
	Avg. market price	48	35.95	7.04
	Lerner Index (MC)	48	0.29	0.17
	Lerner Index (AC)	96	0.28	0.16
	Consumers' surplus	48	9,380,000.00	4,823,628.90

Table 2: Summary statistics

Coverage On average, 80.1% of the areas (77.8% in Co, 70.8% in NoCo and 91.6% in NoCoC) and 85.5% of the households (84.9% in Co, 76.8% in NoCo and 95.0% in NoCoC) are covered. Contrary to the theoretical prediction, there exist differences in coverage between the treatments. Both, with respect to the the covered areas ($F(2,141)=8.07$, $p<0.001$) as well as with respect to the covered households ($F(2,141)=7.28$, $p<0.001$).[9] Table 3 summarizes the results of the pairwise compar-

[9]We employ parametric tests (ANOVA with Tukey's HSD as post-hoc test) to compare treatments throughout the paper to be consistent with the (parametric) regression analysis that follows. However,

isons of the treatments. NoCoC yields the highest coverage of all treatments, whereas the coverage in Co and NoCo are not statistically different. Moreover, it is noteworthy that network infrastructure was on average duplicated in 15.2% of the cases (6.2% in Co, 22.9% in NoCo and 16.7% in NoCoC). In the co-investment treatments common infrastructure was build in 56.3% of the cases. No investment in network infrastructure occured once in Co and three times in NoCo.

Coverage	ANOVA	Tukey's HSD		
		Co-NoCo	Co-NoCoC	NoCo-NoCoC
Areas	$F(2,141)=8.07^{***}$	0.21	-0.42^{*}	-0.63^{***}
HH	$F(2,141)=7.28^{***}$	5625	-7083^{+}	-12708^{***}

$^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.001$, *** $p < 0.001$

Table 3: Differences in coverage between the treatments.

Tacit Collusion The extent of price collusion is evaluated by the deviation of market prices from pertinent costs. By contrast, absolute market prices cannot adequately reflect the extent of price collusion because they depend on the firms' investment decisions in the first stage. More specifically, we measure the extent of price collusion under consideration of the investments in the first stage using two different indices:

1. The usual Lerner index *L(MC)*, which is measured by the relative deviation of prices from the sum of the firm's *marginal costs*, i.e., $L(MC)_t = \frac{p_t-(a_1+a_2)}{p_t}$. Hence, this index indicates by how much the market price departs from the respective price equilibrium.

the reported results also hold qualitatively under the equivalent non-parametric tests (Kruskal-Wallis with Mann-Whitney-U as post-hoc test).

2. A variant of the Lerner index *L(AC)*, which measures the relative deviation of a firm's price from it's underlying *average costs*, i.e., $L(MC)_{i,t} = \frac{p_{i,t}-(a_i+K_i/(T\overline{n}))}{p_{i,t}}$. Consequently, this index relates directly to a firm's profit.

Figure 1 shows that both indices provide consistent results.

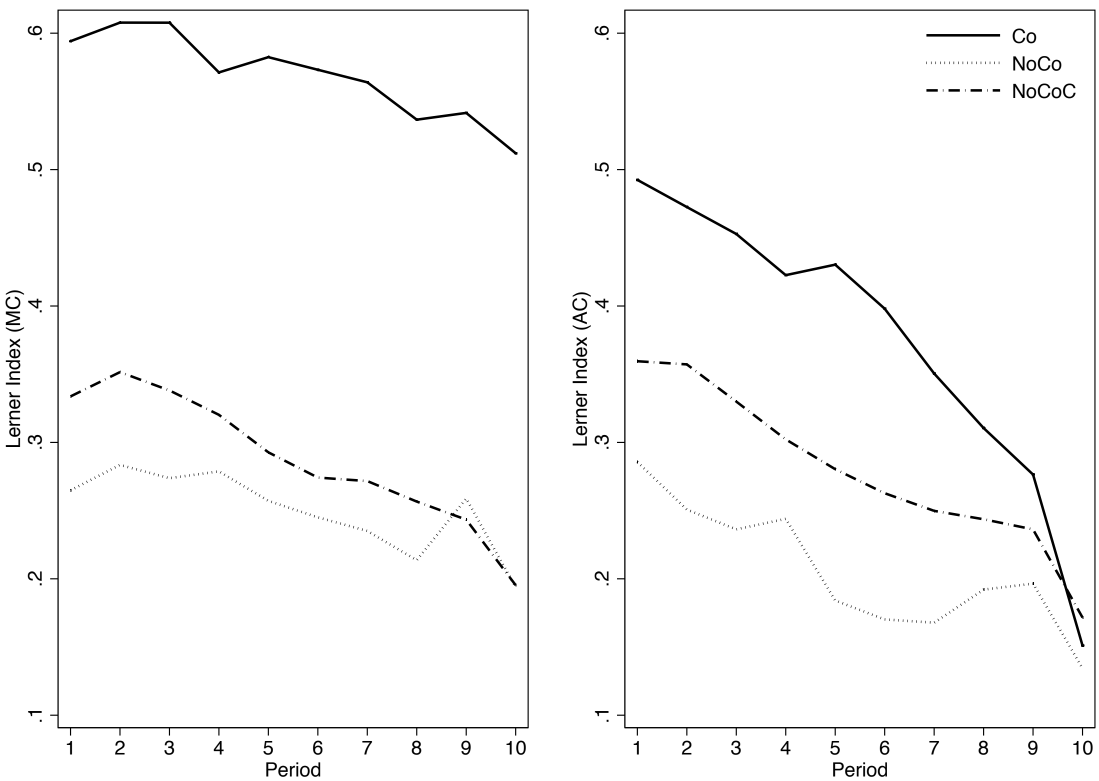

Figure 1: Price collusion over time as measured by the relative deviation of market prices from the equilibrium market price (left) and the relative deviation of prices from average costs (right).

Table 4 provides the detailed statistical results for differences in tacit price collusion based on averages of the above indices from periods 1-5, 6-10 and 1-10. The extent of tacit price collusion is significantly higher in the Co treatment than in the NoCo or NoCoC treatment. In this context, recall that co-investments occur in more than 50% of the cases, which contradicts the theoretical prediction by which co-investments should not occur at all. Co-investments are only reasonable if participants expect that actual market prices will be well above the theoretical prediction. As the left hand side of Figure 1 shows, this expectation holds true ex post. Furthermore, price collusion in NoCoC tends to be higher than in NoCo, however, by and large NoCo and NoCoC are not significantly different in this respect. Finally, it can be observed that tacit collusion tends to decline from period to period. This is most certainly due to the "end-game effect" which results from the fact that firms interact for a predefined and finite number of retail periods. Nevertheless, a fixed time horizon was chosen for our experiments, because the computation of the LRICs require a fixed deprecation period and because otherwise there would be uncertainty about the (ex post) price equilibrium. As will be seen later (Table 5), tacit price collusion increases from round to round although the same firms never interact twice, indicating that firms even learn to collude over time.

Collusion	Periods	ANOVA	Tukey's HSD		
			Co-NoCo	Co-NoCoC	NoCo-NoCoC
L(MC)	1-5	$F(2,137)=16.88^{***}$	$.321^{***}$	$.265^{***}$	-.056
L(AC)		$F(2,277)=22.98^{***}$	$.214^{***}$	$.128^{***}$	$-.086^{*}$
L(MC)	6-10	$F(2,137)=16.50^{***}$	$.316^{***}$	$.297^{***}$	-.019
L(AC)		$F(2,277)=3.38^{*}$	$.125^{*}$	.064	-.061
L(MC)	1-10	$F(2,137)=17.31^{***}$	$.319^{***}$	$.281^{***}$	-.037
L(AC)		$F(2,277)=10.87^{***}$	$.170^{***}$	$.096^{*}$	-.073

* $p < 0.05$, ** $p < 0.001$, *** $p < 0.001$

Table 4: Differences in price collusion between the treatments during the first five, last five and all retail periods.

Consumer Welfare Finally, we take a closer look at how co-investments affect coverage, tacit price collusion and ultimately consumers' surplus (CS). More precisely, CS $= T\overline{n}(v-p)$, where p denotes the average market price.[10] It is obvious that CS is determined endogenously as a result of coverage and prices. Thus, it is subject to a relatively large standard deviation and it is not surprising that there are no statistical differences in CS between the treatments (F(2,141)=0.47, n.s.).

In order to gain a deeper understanding how CS is affected, we study which variables influence coverage and prices by means of a regression analysis (Table 5). Whereas the previous analyses referred only to the differences by treatment (e.g, Co is compared to NoCoC independent of whether co-investment actually occurred), the following regressions are instead ignorant of the treatments, but rather control for the actual differences between them.

At first, we are interested in the factors that increase the coverage, i.e., the number of households that are covered by either firm (HH). We consider four different factors at this stage: (i) the extent of co-investments (in per cent of the total coverage), (ii) the extent of infrastructure duplication (in per cent of total coverage), (iii) whether communication between the firms was possible prior to the investment (i.e., treatments Co and NoCoC) and (iv) the round in which the investment decision was made. Regression (1) in Table 5 shows the results with respect to coverage. Notice that the possibility to communicate, despite being cheap talk, has a positive effect on coverage. On the contrary, co-investments do not lead to more coverage. Of course, communication is inherent to any co-investment, however, over and beyond establishing communication,

[10] Thereby it is assumed that the market price $p_t \leq 50, \forall t$, which was in fact the case for all observations in our experiment.

co-investments do not seem to have an additional effect on coverage. By contrast, duplication of infrastructure is related to a larger coverage. This later result is also supported by existing empirical studies for the USA (Aron and Burnstein, 2003) and Europe (Distaso et al., 2006).

Second, we investigate which factors determine the extent of price collusion. Here we consider only the more conservative collusion measure $L(AC)$ that shows less collusion. However our results are qualitatively the same if $L(MC)$ is considered instead. Next to the controls of the previous regression, total coverage is now incorporated as an additional explanatory variable in the second regression.[11] It is found that tacit price collusion is largely driven by the extent of co-investments, but not by the possibility to communicate. Recall that firms were only allowed to communicate about investments and not about future prices.[12] Yet we find that co-investments facilitate tacit price collusion. Furthermore, the regression confirms the intuition that infrastructure-based competition hinders price collusion. Finally, the extent of price collusion also increases with each round.[13] This is an indication that participants learn to tacitly collude over time, although they never interact with the same firm twice.[14]

[11]It should be noted that the regression may therefore be susceptible to some degree of collinearity between the independent variables, because the dependent variables of the previous regression are now added as an independent variable. However, notice that multicollinearity does not violate any of the Gauss-Markov assumptions underlying the OLS estimation, such that OLS remains the best linear unbiased estimator (BLUE). In particular, the R^2 statistic remains unaffected and a statistically significant coefficient can be interpreted in the usual way (see Kennedy, 2008, p. 193). Moreover, Table 6 in the appendix reports the pairwise correlations between all variables used in the regressions and shows that all correlations are below the threshold of 0.5. Thus, multicollinearity should not have a significant effect on our results.

[12]Also a deeper analysis of the chat protocols revealed no significant pattern or keyword that could explain price collusion. For example, neither the length of chat messages nor the mentioning of the keyword "price" in any context was found to have an effect on the extent of tacit collusion.

[13]This is in contrast to the collusion within each round that tends to decline from period to period.

[14]Notice that standard errors were clustered by session, which, in conjunction with the inclusion

Finally, the total effect on prices is considered in the third regression. It can be seen that the observed market price is the result of several opposing effects. First, as one would expect, more infrastructure-based competition (ceteris paribus) leads to lower market prices. Second, it is also intuitive that market prices increase with the extent of price collusion. Third, although co-investments are a driver of tacit collusion, which is shown in the second regression, it is interesting to observe that co-investments (net of price collusion) tend to decrease the market price. Thus, it may be concluded that co-investments have two opposing effects on the observed market price. On the one hand, co-investments mitigate price competition and thereby increase the market price. On the other hand, co-investments lower the firms' average and marginal costs and thereby decrease the market price. As a result, market prices under co-investment are not as low as one would expect in the presence of effective price competition.

Hence, our results indicate that co-investments may only be expected to have a positive effect on CS if price collusion is held in check. In this case the cost lowering effect of co-investments dominates and market prices are likely to be lower. However, co-investments (net of communication) do not seem to be a determinant of network coverage. Instead, communication, which is inherent to co-investments, is found to be the actual driver of investment.

In reverse, real infrastructure-based competition is found to have an unambiguously positive effect on CS. It tends to lead to more coverage, less tacit collusion and lower (hedonic) prices. Thus, with respect to CS, co-investments are only a second-best alternative.

of *round* in the regression, should effectively control for any feasible interdependence between the observations within any one session.

	(1) HH	(2) L(AC)	(3) Price
Collusion (L(AC))			0.423*
			(2.88)
Coverage (HH)		0.205	-0.109
		(1.93)	(-0.99)
Co-investment (%)	-0.076	0.405*	-0.415**
	(-1.08)	(2.74)	(-3.54)
Duplication (%)	0.155*	-0.384**	-0.250*
	(2.28)	(-3.21)	(-2.83)
Communication	0.267*	-0.010	0.117
	(2.73)	(-0.10)	(0.81)
Round	-0.029	0.238**	0.036
	(-0.58)	(4.32)	(0.71)
Observations	140	140	140
R^2	0.075	0.424	0.358

Standardized beta coefficients; t statistics in parentheses
Cluster-robust standard errors adjusted by session
* $p < 0.05$, ** $p < 0.01$

Table 5: OLS regressions of household coverage (HH), price collusion (L(AC)) and average market price (price).

6 Discussion and Conclusions

Co-investments in network industries are commonly considered to foster investments in network infrastructure in the presence of high sunk costs. At the same time, co-investments are believed to create a competitive environment that is akin to infrastructure-based competition.

However, our results of a laboratory experiment indicate that co-investments do *not* stimulate investment in network infrastructure beyond the level that is achieved by access regulation based on LRIC. Nevertheless, if allowed, co-investment is employed in 50% of the cases in which it has an ambivalent effect on prices. On the one hand, co-investments facilitate price collusion and therefore tend to increase prices. This effect is neglected in most theoretical papers like Nitsche and Wiethaus (2011). On the other hand, co-investments reduce the firms' costs and thereby tend to reduce prices. Both effects are about equally strong, such that the resulting market prices are similar to those under plain access regulation. However, communication between the firms on their future coverage, which is a prerequisite for co-investments, seems to have a positive effect on investments. In contrast, the fear that communication between the firms during the investment stage might facilitate price collusion cannot be substantiated. Beyond having a positive effect on coverage, which positively affects consumers' surplus, communication did not negatively affect prices in our experiments. It is important to highlight, however, that a Chinese wall approach was adopted with respect to communication, i.e., the firms were only allowed to communicate about investments and not about prices. Such a strict ban on communication may be hard to sustain in reality.

While it remains a mystery from a theorist's point of view why prices are systematically higher in the co-investment treatment, from a more psychological point of view, one might argue that the chat generates some familiarity between the two firms that may facilitate tacit collusion. However, this would also have to hold for the NoCoC case. In contrast, the fact that co-investment happens may generate a bond between the firms that is absent under chat only. Given our data, this is mere speculation.

In addition, the level of collusion increases over the four independent rounds that are played. We can only hypothesize that there was some type of learning going on, i.e., learning to tacitly collude. The round effect is only present for collusion and not for any other variable.Tacit collusion may also have been triggered by the uniform pricing assumption. According to Dobson and Waterson (2008) a uniform pricing commitment can soften competition. This effect would be present in all scenarios, though.

Finally, we should emphasize more clearly that we do find a substantial level of tacit collusion although we made almost every effort to prevent it. We introduced i) Chinese Walls ii) asymmetry (at equal prices the incumbent gets 75% of the market share) iii) a perfect stranger matching (i.e., no repeated interaction) and yet we find collusion. The only thing that we did not do is vary the number of firms in the market. Obviously collusion is harder to sustain with three or more firms. But from what we know so far, if we are lucky, at best two firms are realistically going to co-invest in telecommunications infrastructure.

In conclusion, our laboratory study has shown that the effect of co-investments on coverage and competition in network industries is ambiguous. On the one hand, co-investments are not a significant driver of new infrastructure investments beyond the level achieved by access regulation and seem to facilitate tacit price collusion. On the other hand, co-investments economize on infrastructure investment costs and necessitate communication, which partially offset the aforementioned effects with respect to consumers' welfare. By contrast, we find that duplication of infrastructure, which allows for actual infrastructure based competition, has an unambiguously positive effect on consumers' surplus. Everything else equal, infrastructure based competition leads to more coverage, lower retail prices and thus higher consumer welfare. Therefore, our results indicate that regulators should evaluate the possibility to allow co-investments with scrutiny as there are definite drawbacks that must be considered.

Obviously, our study also has several limitations. First, although we can point at the opposing effects that co-investments may have on consumers' welfare, we cannot determine which effect will prevail in reality. Our experiment was designed in a way that should mitigate tacit collusion (asymmetric payoffs, perfect stranger matching, Chinese walls), but collusion was nevertheless found. Thus, we find a strong case for tacit collusion in the context of co-investments. Still there might be other factors that drive price collusion which were not considered in this study. For example, there is reason to believe that tacit collusion is harder to sustain with more firms Huck et al. (2004). However, a co-investment consortium of more than two firms may also be much harder to establish, which may limit the extent of co-investment considerably in the first place.[15] This trade off may be considered in more detail by future work. Second, in reality firms may find it easier to finance co-investment projects. Not only because they need less capital than independent investments, but also because the risk of infrastructure duplication is lower. These financial constraints, which may increase the likelihood that co-investments lead to more network coverage than independent investments, were not considered in our analysis. Third, we have made the simplifying assumption that firms must set the same retail price in all coverage areas. To date, this assumption seems to be empirically justified for Europe, where network operators rarely differentiate prices for the same access product between different regions. Never-

[15] Co-investment with larger numbers of participants can, however, happen in other industries, such as natural gas pipelines.

theless, in the context of regionally differentiated regulation, this practice may change and it would be interesting to investigate which effect the required price uniformity across regions has on investments and collusion. This would also take care of the must serve obligation. Finally, it may also be worthwhile to evaluate alternative means to foster network infrastructure investments with the use of a laboratory experiment. For example, it would be interesting to compare the present results to different modes of access regulation, e.g., regulatory holidays or LRIC with different interest rates (γ). Particularly, the latter could provide valuable insights in the context of the regulatory debate on the appropriate 'allowed rate of return' (Cambini and Jiang, 2009).

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A Experimental Instructions

The following experimental instructions are for the co-investment treatment and were translated from German. The instructions for the other treatments are identical except with respect to the specifics of the treatment, i.e., the possibility to chat or joint development.

Preliminary Remarks

Welcome to the experiment and thank you very much for your participation. If you read through these instructions carefully and consider them during the experiment, you can earn an amount of money that depends on your decisions and the decisions of the other participants. Please address the person in charge of the experiment in case of questions. Please do **not** talk to the other participants during the entire experiment.

We will denote the payoffs in monetary units (MU) during the experiment. The MU that you will have earned by the end of the experiment will be converted into EURO and will be paid to you in cash (1M MU $\hat{=}$ 1 EURO).

Setup of a Round

The experiment is divided into several rounds. The decisions and the results of each round are not interdependent. In each round, you will simulate the decision of a firm that sells a **utility good** (e.g. gas, water, telecommunication services, or electricity) to private households (HH). There is exactly **one other firm** apart from you (which will be called "the other firm" in the following). You will be competing against this other firm.

In each round, you and the other firm have an **initial budget of 18M MU**. A network, which is necessary to sell the utility good, does not yet exist. You and the other firm can develop the network in the first phase of the experiment (**investment phase**).

In the following phase, the **retail phase**, you can sell the utility to all households that are connected to the network. In doing so, it does not matter whether the households are connected to your own network or to the network of the other firm. You can use the network of the other firm for selling your good by buying a line rent, which will be described in detail later on.

For simplification reasons, you can assume that the utility good can be **produced without generating any costs**, and that you agree on a **flat rate** with the households. You and the other firm produce equal goods. Therefore, the consumers will buy the good from the firm that offers the good at a **lower price**. The households are willing to pay a **maximum of 50 MU** for the utility good.

Investment Phase

There are three areas, in which you and the other firm can develop the network. The number of households that you can sell your good to differs in the three areas. 40000 HH are located in **area I** (city center). 20000 HH are located in **area II** (suburbs). And 10000 HH are located in **area III** (rural areas). The investment phase is divided into two separate parts. In the first part, you and the other firm make a common decision in which of these areas a **joint network** is to be developed (joint development)—in the second part, you decide in which areas you want to develop your **own network** (own development).

The decisions regarding the development of the own network are being made **one after the other** by you and the other firm. The firm that can choose first in which areas to invest is called the **Established Firm**. The firm that decides second is called the **New Firm**. It will be chosen at random whether you will be the Established Firm or the New Firm, i.e., whether you decide before or after the other firm. You will be informed about the sequence of the decisions already before the joint development. The two parts of the investment phase are explained in detail in the following.

First Part: Joint Development

In the first part of the investment phase, you and the other firm have to agree on whether or not to develop a joint network and in which areas to develop the network. The costs for a joint development of an area amount to **4.5M MU for the Established Firm and to 1.5M MU for the New Firm**, regardless of the number of households located in that area. The network that you develop together with the other firm can be used by you and the other firm for free. You will have to agree upon one of the following development options:

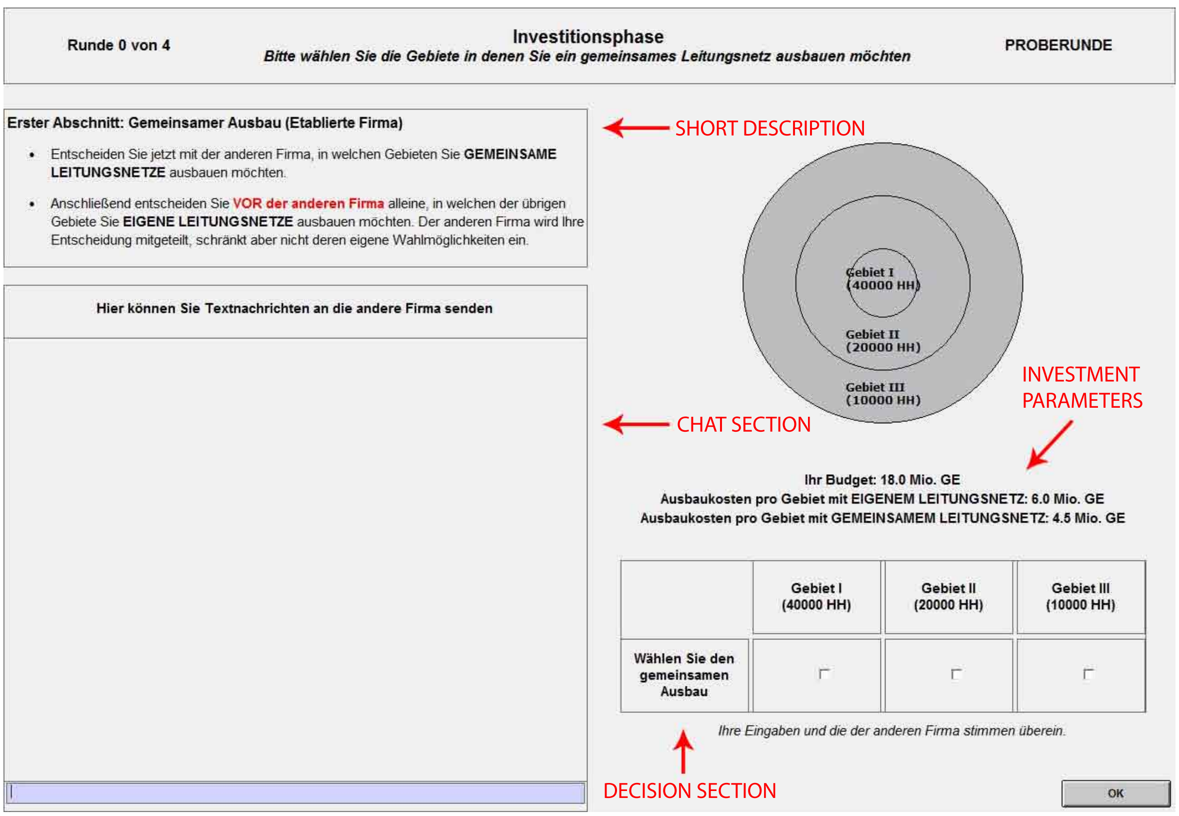
- not to make a joint development,
- a joint development of one area,
- a joint development of two areas, or
- a joint development of all three areas.

The level of the investment costs in the first part depends on this decision and on whether you are the Established Firm or the New Firm.

	Budget	Investment costs with no joint development	Investment costs with joint development of one area	Investment costs with joint development of two areas	Investment costs with joint development of three areas
Established Firm	18 $M\ MU$	0 MU	4.5 $M\ MU$	9 $M\ MU$	13.5 $M\ MU$
New Firm	18 $M\ MU$	0 MU	1.5 $M\ MU$	3 $M\ MU$	4.5 $M\ MU$

The development decision is binding. It is not possible to change the decision in the course of this round.

Software display during the first part of the investment phase



The image shows the display of the experiment software during the first part of the investment phase. The display includes the following components:

- The **short description** summarizes the main instructions and indicates whether you will be first or second to decide on the development of an own network.
- The **investment parameters** sum up the most relevant decision variables.
- In the **chat section**, you can send text messages to the other firm. Please communicate via chat with the other firm in order to decide upon the joint development. You may also use the chat to make agreements with the other firm with respect to the own developments. However, notice that such agreements are not binding. Neither for you, nor for the other firm. **Agreements about prices during the retail phase are strictly prohibited.** If you should make such agreements on prices or reveal your identity, you will be excluded from the experiment immediately. Please type your text message in the dark-grayed out field at the bottom of the screen and press the Enter key in order to send a text message.
- In the **decision section**, you can indicate which areas you want to develop jointly by checking the boxes. Please confirm by clicking on the OK button. You can only continue, if your input is consistent with the input of the other firm.

Second Part: Own Development

You can develop your own networks in the remaining areas after the joint decision with the other firm. The costs for the own development of an area amount to **6M MU**, regardless of the number of households located in that area. Only you can use your own network for free.

The decisions regarding the development of the own network are being made one after the other by you and the other firm. It will be chosen at random whether you will decide before or after the other firm. The firm that comes second will be informed about the development decision of the other firm. It can then react accordingly when making its own development decision. The options of the firm that comes second are not limited by the decision of the first firm—i.e., both firms can develop in the same area. Please consider, however, that two different networks are developed in that case. Hence, the development costs are 6M GE per area and firm. A joint development as in the first part is not possible in the second part of the investment phase.

Depending on your decision in the first part, one or some of the following options are feasible:

- not to develop on your own,

- develop one area yourself,
- develop two areas yourself, or
- develop all three areas yourself.

The level of the overall investment costs depends on the decisions in the first and in the second part and on whether you are the Established Firm or the New Firm. Your intital budget minus the investment costs will be added at the end of each round to your revenues from the retail phase.

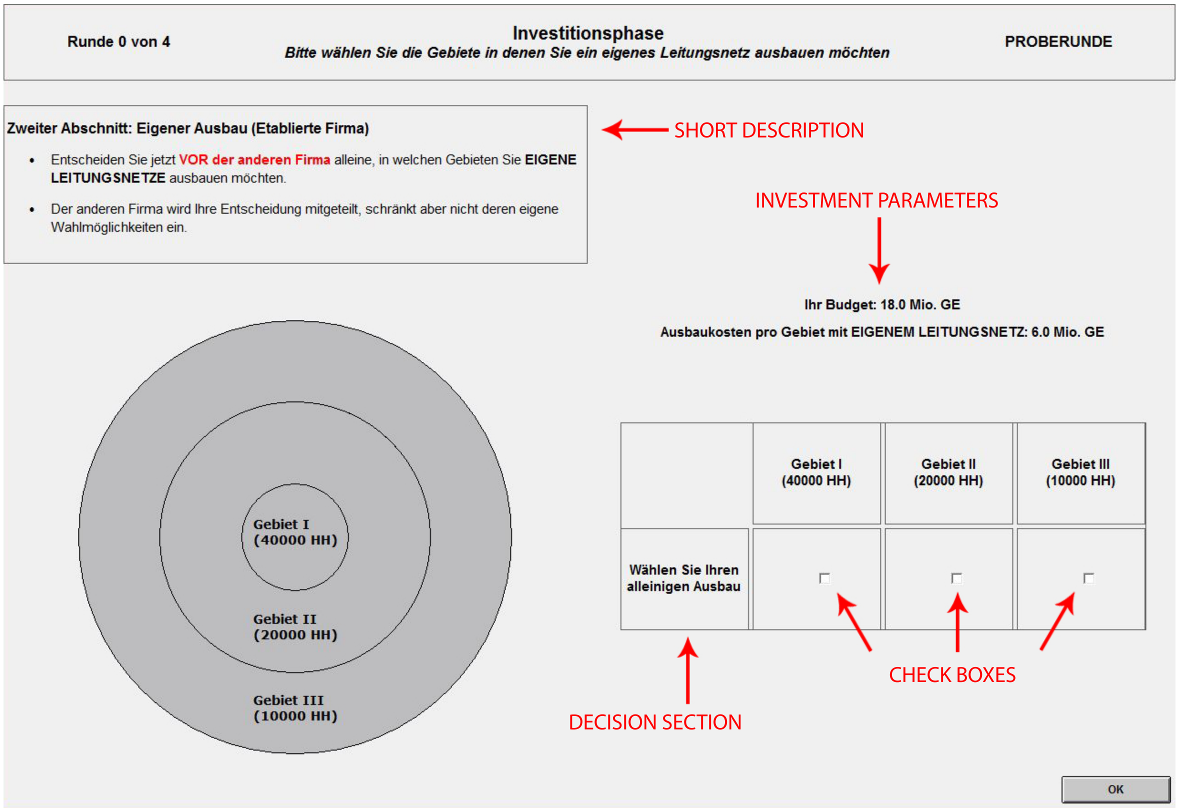
Investment costs as Established Firm with...		Own development			
		0 areas	1 area	2 areas	3 areas
joint development	0 areas	0 *MU*	6 *M MU*	12 *M MU*	18 *M MU*
	1 area	4.5 *M MU*	10.5 *M MU*	16.5 *M MU*	
	2 areas	9 *M MU*	15 *M MU*		
	3 areas	13.5 *M MU*			

Investment costs as New Firm with...		Own development			
		0 areas	1 area	2 areas	3 area
joint development	0 areas	0 *MU*	6 *M MU*	12 *M MU*	18 *M MU*
	1 area	1.5 *M MU*	7.5 *M MU*	13.5 *M MU*	
	2 areas	3 *M MU*	9 *M MU*		
	3 areas	4.5 *M MU*			

Software display during the second part of the investment phase

The image shows the display of the experiment software during the second part of the investment phase. Exemplarily, the display is shown for the firm that gets to choose first on the development of an own network. The display includes the following components:

- The **short description** summarizes the main instructions and indicates whether you will be first or second to decide on the development of an own network.
- The **investment parameters** sum up the most relevant decision variables
- In the **decision section**, you can indicate which areas you want to develop by checking the boxes. Please confirm by clicking on the OK button. If your firm is second to choose, the choice of the other firm will be communicated in the decision section. If you have made a joint development, the appropriate boxes are already selected.



Retail Phase

If at least one of the two companies develops a network during the investment phase, the retail phase consisting of **10 retail periods** follows the investment phase. In each retail period, you offer your utility good to all households connected to the network. Hence, you can also sell the utility good to households that are located in those development areas in which only the other firm has a developed network.

You are **legally bound** to sell your utility good **in all development areas** at the **same price**.

Demand

All households will always demand the utility good that is offered at the lower price. However, they are not willing to pay more than 50 MU per retail period. If you offer your good at a higher price than the other firm, there will be no direct demand for your good. The same applies if one of the two companies offers the good at a price higher than 50 MU. If both firms offer the same price, then the Established Firm will receive 75% and the New Firm 25% of the total demand. If both prices are above 50 GE, there will be no demand for both firms.

Renting and Renting Out Lines

If a firm needs to respond to demand, but does not have an own or joint network in all developed areas, it has to **rent lines** from the other firm. The rental fee that needs to be paid is regulated by law and guarantees a **10% rate of return on the investment** made by the firm. The line rent per household and retail period is calculated as follows:

$$Line\,rent = \frac{Your\ investment\ costs}{\#\ your\ connected\ households} \cdot \frac{1\ +\ rate\,of\ return}{\#\ of\ retail\ periods}$$

The number of connected households refers to those households that are connected to an own or joint network. In the case of ten retail periods and a rate of return of 10%, the lines rent is:

$$\begin{aligned} Line\,rent &= \frac{Your\ investment\ costs}{\#\ of\ your\ connected\ households} \cdot \frac{1.1}{10} \\ &= \frac{Your\ investment\ costs}{\#\ of\ your\ connected\ households} \cdot 0.11 \end{aligned}$$

Examples for the Calculation of the Line Rent

Only one firm makes investments

Firm A has invested 6M MU in area I (40000 HH). Firm B did not make any investments. A possesses the entire available network and does not have to rent any lines. Hence, firm A does not have to pay rent to firm B. As a result, the incoming line rent for firm B amounts to 0 MU.

Firm B, on the other hand, has to rent lines from firm A if there is a demand for the good of firm B. The incoming line rent for firm A—hence, the rent that firm B has to pay—for the lines in area I amounts to: :

$$\frac{6\,M\,MU}{40000\,HH} \cdot 0.11 = 16.5\,\frac{MU}{HH}$$

Please remember: This line rent has to be paid only for those households that are not connected to an own network.

The firms make joint investments and different own investments

The firms make the same investment in a joint network, and different investments in own networks. Firm A (Established Firm) and B (New Firm) make a joint investment in area I (40000 HH). Firm A develops an own network in area II (20000 HH). Firm B develops an own network in area III (10000 HH). Thus, the total investment costs of firm A are 10.5 M MU and of firm B 7.5 M MU.

The incoming line rent for firm A—hence, the rent that firm B has to pay—for the lines in area II amounts to:

$$\frac{10.5\, M\; MU}{60000\, HH} \cdot 0.11 = 19.25\, \frac{MU}{HH}$$

The incoming line rent for firm B—hence, the rent that firm A has to pay—for the lines in area III amounts to:

$$\frac{7.5\, M\; MU}{50000\, HH} \cdot 0.11 = 16.5\, \frac{MU}{HH}$$

Both firms make the same investments

If firm A and firm B invest in the same areas (regardless of whether they invest in a joint network or in own networks), they both do not have to pay any line rent as each firm can offer its utility good to all connected households by using their own network or the joint networks. The lines rent amounts to 0 GE respectively.

Please note: The software calculates your incoming and outgoing line rent payments automatically based on the investment decisions. The corresponding information is being displayed during the retail phase.

Depending on your investment costs and the number of your connected households, several different line rent payments result when using the above-mentioned formula for the calculation of the incoming line rent.

Incoming line rent as Established Firm in $\frac{MU}{HH}$ with...		Your investment costs								
		4.5 *M MU*	6 *M MU*	9 *M MU*	10.5 *M MU*	12 *M MU*	13.5 *M MU*	15 *M MU*	16.5 *M MU*	18 *M MU*
Number of your connected households	10000 HH	49.50	66							
	20000 HH	24.75	33							
	30000 HH			33	38.50	44				
	40000 HH	12.38	16.50							
	50000 HH			19.80	23.10	26.40				
	60000 HH			16.50	19.25	22				
	70000 HH						21.21	23.57	25.93	28.29

Incoming line rent as New Firm in $\frac{MU}{HH}$ *with...*		Your investment costs								
		1.5 M MU	3 M MU	4.5 M MU	6 M MU	7.5 M MU	9 M MU	12 M MU	13.5 M MU	18 M MU
Number of your connected households	10000 HH	16.50			66					
	20000 HH	8.25			33					
	30000 HH		11			27.5		44		
	40000 HH	4.13			16.50					
	50000 HH		6.60			16.50		26.40		
	60000 HH		5.50			13.75		22		
	70000 HH			7.07			14.14		21.21	28.29

Please note: These incoming rent payments only apply to lines in areas, in which the other firm did **not** develop an own network. Hence, it depends on the development of the other firm, whether or not you will receive any rent payments.

Revenues and Expenses

During the retail periods, you have, in general, two possibilities to generate revenues:

1. **By selling the utility good directly to the households in the developed areas:** This applies if there is demand for your good, i.e., your price is not higher than the price of the other firm and your price does not exceed 50 MU.

2. **By renting out your own network to the other firm:** This applies if there is demand for the good of the other firm and you are the only firm that has developed a network in at least one area.

When renting out own lines, you receive a fixed return of 10% on your investments. When selling directly to households, the return depends on the price that can be achieved on the market. This price will depend on the investments and the degree of competition to the other firm. Therefore, **the return on sales can be higher or lower than the return on renting out**.

It is also possible that you **achieve revenues from direct sales and from renting out at the same time**. This is the case if you offer the utility good at the same price as the other firm and you are the only firm that has developed lines in at least one area. Hence, there exist different cases of generating revenue depending on role as Established or New Firm, your development and your price as well as the development and the price of the other firm.

	Your price > price of other firm	Your price = price of other firm	Your price < price of other firm
No own development	No demand, no reveneus	75% / 25% demand, revenues from direct sales, expenses for renting	Full demand, revenues from direct sales, expenses for renting
Different development	No demand, revenues from renting out	75% / 25% demand, revenues from direct sales and renting out, expenses for renting	Full demand, revenues from direct sales, expenses for renting
Equal development	No demand, no revenues	75% / 25% demand, revenues from direct sales	Full demand, revenues from direct sales

Software display during the retail phase

The display of the experiment software is divided into four sections during the 10 retail periods. These sections are explained in the following.

Investment decisions and accumulated revenues In this section,

- the investment decisions of both companies are shown on the left,
- the resulting investment parameters (investment costs, connected households, and line rent payments) are shown in the middle, and
- the accumulated revenues of all previous retail periods are shown on the right.

	Gebiet I (40000 HH)	Gebiet II (20000 HH)	Gebiet III (10000 HH)	Investitionskosten	Restliches Budget	Erreichbare Haushalte über EIGENE Leitungen	Erreichbare Haushalte INSGESAMT	Eingehende Miete bei fremder Nutzung	Kumulierte Einnahmen aller Perioden
Ihre Firma	X			6.0 Mio. GE	12.0 Mio. GE	40000 HH	60000 HH	16.50 GE/HH	**0.000 Mio. GE**
Die andere Firma		X		6.0 Mio. GE	12.0 Mio. GE	20000 HH	60000 HH	33.00 GE/HH	**0.000 Mio. GE**

Retail history The main parameters of the past retail periods are shown in this section:

- the price of your firm and the price of the other firm
- your demand
- your selling revenues: turnover (price · demand) from direct sales minus the line rent that might have to be paid
- your revenues from renting out lines to the other firm

- overall revenues (= retail revenues+incoming rent payments) of this retail period for your firm as well as the other firm

	Periode 1	Periode 2	Periode 3	Periode 4	Periode 5	Periode 6	Periode 7	Periode 8	Periode 9	Periode 10
Ihr Preis	0 GE	0 GE	0 GE	0 GE	0 GE	0 GE	0 GE	0 GE	0 GE	0 GE
Anderer Preis	0 GE	0 GE	0 GE	0 GE	0 GE	0 GE	0 GE	0 GE	0 GE	0 GE
Ihre Nachfrage	0 HH	0 HH	0 HH	0 HH	0 HH	0 HH	0 HH	0 HH	0 HH	0 HH
Ihre Einnahmen aus Verkäufen	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE
Ihre Einnahmen aus Vermietung	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE
Ihre Gesamt-Einnahmen	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE
Andere Gesamt-Einnahmen	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE	0.000 Mio. GE

Testing the consequences of the pricing decision You can test the consequences of your pricing decision in this section. In order to do so, you have to indicate your price as well as what you expect the price of the other firm to be by using the slider. As soon as you drop the slider, the values in the table beneath are being updated. The table shows the effects of the respective price combination on the demand and on the revenue in one retail period. Just like in the retail period,

- the retail revenues (= gross revenue – rent payments),
- the revenues from renting out, and
- the overall revenues

are being shown.

Hier können Sie die Konsequenzen Ihrer Preisentscheidung dieser Verkaufsperiode testen

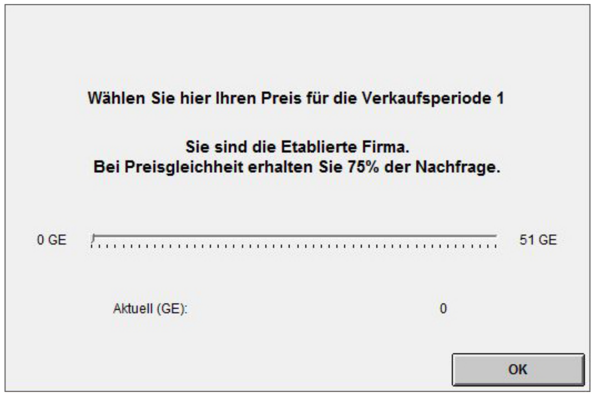
Ihr Preis: 0 GE – 51 GE
Aktuell (GE): 0

Preis der anderen Firma: 0 GE – 51 GE
Aktuell (GE): 0

	Nachfrage (HH)	Einnahmen aus Verkäufen (Mio. GE)	Einnahmen aus Vermietung (Mio. GE)	Gesamteinnahmen (Mio. GE)
Ihre Firma	0	0.000	0.000	0.000
Die andere Firma	0	0.000	0.000	0.000

Please note: You can not only use this section in order to test the effects of your own pricing decision, but also to estimate the possible reactions to your current pricing decision of the other firm.

Pricing Decision You can determine your selling price for the current retail period in this section. Move the slider to your desired price and confirm by clicking on the OK button. It is shown to you whether you will receive 75% or 25% of the demand at equal price, i.e., whether you are the Established Firm or the New Firm.



Course of the Experiment

Overall, **5 rounds** (0 to 4) are being played. Round 0 is a test run. Each round consists of an investment phase and a retail phase (10 retail periods). The firm pairings are being randomly determined all over again in each round. However, it is excluded that you will ever play again with the same firm.

The information regarding the round and the course of the experiment are always being shown at the top level of the screen.

At the end of each round, your budget minus the investment costs, your accumulated revenues of the 10 retail periods and your payment (= initial budget − investment costs + accumulated revenues) from this round are being shown in MU as well as in EURO. You do not have to memorize these values. At the end of the experiment, the payment of exactly one round is being paid to you. It will be chosen at random which of the rounds is being cashed out. In order to do so, you will have to roll a dice. The test run, round 0, is not included.

Concluding Remarks

Do not hesitate to ask questions. As long as they refer to these instructions and not to possible strategies, we will answer your questions as far as possible. Please remember: The better you have understood these instructions, the more money you can make.

Before the experiment starts, you will be asked some questions on the screen with regard to the understanding of the rules and the course of the experiment. Please enter the respective answer into your computer. Afterwards, the experiment will start automatically.

In case of any additional questions during the experiment, please remain seated and give the person in charge of the experiment a hand signal. Please wait until the person in charge of the experiment has arrived at your seat. Talk as quietly as possible when asking the question. Please remain seated after the end of the experiment as well and wait for further instructions from the person in charge of the experiment. You can make notes on the pad that is laid out for you on the table during the experiment. Please leave the experiment instructions, the calculator as well as the note pad at the table after the experiment.

B Statistical Appendix

	Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1)	Price	1.00						
(2)	Collusion (L(AC))	0.37	1.00					
(3)	Coverage (HH)	-0.05	0.15	1.00				
(4)	Communication	0.12	0.24	0.25	1.00			
(5)	Co-investment (%)	-0.17	0.43	-0.01	0.32	1.00		
(6)	Duplication (%)	-0.42	-0.44	0.11	-0.21	-0.13	1.00	
(7)	Round	0.20	0.23	-0.01	-0.00	-0.09	-0.10	1.00

Table 6: Cross-correlation table