# OPEN ACCESS TO TELECOMMUNICATIONS INFRASTRUCTURE AND DIGITAL SERVICES: COMPETITION, COOPERATION AND REGULATION

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# Abstract

Open Access, defined as the non-discriminatory access to an upstream bottleneck resource, takes a central role in information and communications technology markets with its direct and indirect ramifications on competition and innovation. Moreover, recent technological innovations have fundamentally affected i) the market structure and regulatory paradigm at the infrastructure layer, where Open Access safeguards access to communications access networks, and ii) the evolution of digital services markets, where Open Access is discussed with regard to immaterial upstream bottleneck resources such as data or intellectual property.

This thesis investigates the competitive and cooperative interactions in these markets, where firms require access to an essential input resource. Thereby, theoretical analyses and experimental evaluations are employed to examine market outcomes under alternative regulatory institutions. In particular, experiments in continuous time are utilized to allow for oligopoly competition with asynchronous strategic interaction. Serving as a testbed for policy proposals, the thesis aims at identifying welfare implications of designated regulatory institutions and informing the design of new institutions prior to implementation in the field.

Based on a unified framework for Open Access regulation, margin squeeze regulation, which has recently been emphasized as an alternative to wholesale price regulation in the European Union regulatory framework for telecommunications infrastructure, is scrutinized. The theoretical and empirical analyses in this thesis demonstrate that in the case of infrastructure competition, margin squeeze regulation may benefit non-integrated retailers in specific cases, but never benefits consumers. Thus, in contradiction to the rationale underlying the current legislative implementation in Europe, com-

peting infrastructures do not represent exogenous competitive constraints, but increase retail prices strategically in anticipation of the regulatory rules.

In the case of wholesale competition, access for a retailer may be provided competitively by two vertically integrated firms. Remarkably, in a continuous time economic laboratory experiment, wholesale and retail prices are found to be higher under wholesale competition than under a wholesale monopoly. The finding that consumers are worse off under competition is rationalized by an investigation of collusion incentives. Moreover, a complementary price commitment rule is found to substantially reduce tacit collusion. A validation study with expert participants provides support that experimental outcomes are indeed similar to the student sample. These results point to a dilemma of the Open Access rationale: whereas non-discrimination may provide the basis for competition on equal terms, symmetry may facilitate coordinated behavior among competitors to the detriment of consumers.

The effect of the number of firms on tacit collusion, a central concern in merger control proceedings, is further examined by means of an empirical meta-analysis and two experimental studies. It is shown that tacit collusion decreases strictly with the number of competitors in industries with two, three and four firms. Although previous experimental studies could not affirm that tacit collusion is higher in markets with three than with four firms, evidence for this fact can be provided for symmetric and asymmetric firms, and under Bertrand and Cournot competition.

Finally, voluntary access relationships in digital services markets are explored. To this end, the competitive effects of social logins that allow for the sharing of user and usage data between online content providers and a social network are analyzed theoretically. It is shown that content providers may adopt a social login even if this strategic decision makes them ultimately worse off, i.e., they find themselves in a prisoner's dilemma-like situation. Thus, market failures may occur due to the discriminatory access by the social network. In this vein, voluntary access may be offered by a dominant gatekeeper to protect its position, albeit not through exclusion, but through exploitation. This calls for consideration of Open Access institutions at the digital services layer.

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# Preface

IN the European telecommunications sector, the Open Access (OA) concept represents a well-known cornerstone of the regulatory framework, established during the liberalization and privatization of the industry (Farrell and Weiser, 2003). Guided by the *Ladder of Investment* rationale (Cave and Vogelsang, 2003; Cave, 2006a), access and price regulation has been implemented to foster competition and investments by entrants such that regulation could be lifted stepwise and ultimately as a whole. Fixed and mobile telecommunication markets quickly grew in the 1990s and early 2000s, while entrants relying on regulated access to the incumbent's network were able to capture significant market shares. However, these trends have slowed down significantly or have even been reversed more recently (European Commission, 2014b). Moreover, technological advancements in this period have tremendously improved the technical capabilities of the network infrastructure, but have also fundamentally altered the provisioning of services on top of these networks. In particular, *digital convergence*, i.e., the implementation of the Internet Protocol (IP) as a uniform network standard in combination with a layered protocol architecture, modular composition of end-to-end connections, and infrastructure-transparent services, has laid the foundation for distributed digital services and a globally connected information system.

In consequence, the telecommunications infrastructure today serves a much more general class of digital information services rather than only communications services. On the one hand, the success of these online information services has direct implications for telecommunications providers' business models and possible cooperative strategies. In particular, as complementary goods they increase demand for access services at the network layer. Yet, in contrast, as substitutes they represent additional competitive constraints, especially in the case of communications services. On the other hand, access networks may be affected indirectly by the increased public attention and ensuing policy considerations due to their role as gateways to the Internet and to the respective digital services (see, e.g., the public debate on net neutrality summarized by Krämer et al., 2013). More specifically, the following stylized trends summarize how business models and competitive strategies in the telecommunications markets have been altered by technological progress and adjusted policy considerations. As will be discussed subsequently, these trends question traditional regulatory practice and the outlines of the original sector-specific regulatory framework with the advent of *next-generation access networks (NGANs)*. Although not complete, the listed trends call for a reconsideration of the role, the objectives and the design of regulatory OA regimes at the telecommunications infrastructure layer.

### Trends at the telecommunications infrastructure layer

*1) Infrastructure competition:* Based on the IP standard, different next-generation access (NGA) platforms, which have initially been built for distinct services such as telephony and cable television, are able to deliver digital communications and information services to consumers at fixed locations (De Bijl and Peitz, 2008). In consequence, ensuing infrastructure competition challenges the traditional notion of the fixed local access network as a natural monopoly (Vogelsang, 2013). In addition, different geographical footprints of those networks in combination with the emergence of regional operators have led to a situation where the number of competitors differs geographically (Bourreau et al., 2015). Therefore, in densely populated areas, consumers can choose from several operators, which are each in possession of their own distinct network infrastructure. The market structure in fixed telecommunications thus starts to resemble the market structure in mobile telecommunications, where a low number of infrastructure competitors compete strategically at the retail level and possibly at the wholesale level. Thus, wholesale competition on the basis of infrastructure competition may facilitate voluntary wholesale access for independent retailers and virtual network operators (Ordover and Shaffer, 2007; Bourreau et al., 2011). The entry of network operators relying on a distinct infrastructure may alleviate concerns about exploitation of market power by a single dominant firm, but instead, *tacit collusion*, i.e., the implicit coordination of firms' behavior to the detriment of consumers, may become the central concern of regulators and antitrust authorities in an oligopolistic market structure (Parker and Röller, 1997; Ivaldi et al., 2003).

*2) Next-generation access technologies:* The availability of new high-bandwidth technologies, in particular fiber optics (Kazovsky et al., 2007; Wong, 2012), as well as the development of upgrade solutions for existing technologies, such as Vectoring (Broadband Forum, 2012) and Fiber to the Distribution Point (Broadband Forum, 2015), allow for transmission speeds of several orders of magnitude higher than legacy communications network technologies. At the same time, growing demand for new digital services and continued digitization of traditional physical goods industries reinforce the need for the rollout of NGANs based on these technologies (European Commission, 2016b). With regard to the policy objectives that guide regulatory intervention at the European Union (EU) level, these requirements have begun to shift the focus from competition to a dual emphasis on both competition and investments (see, e.g., Kroes, 2012).

*3) Virtual network operators:* The existence of different NGA technologies in practice increases the heterogeneity of potential wholesale access products across geographic locations (Bundesnetzagentur, 2011). At the same time, virtualization at the network layer allows for the specification of harmonized access products across technologically heterogeneous infrastructures, which may serve as the technological foundation for (cross-border) competition in a European digital single market (European Commission, 2013e, 2015a). In combination, both trends have enabled new operator models and access offers at different levels of the fixed infrastructure and network operations value chain (Dewenter and Haucap, 2006; Banerjee and Dippon, 2009). Thus, multiple virtual network operators and therefore competition may be sustained on top of few or even a single infrastructure.

*4) Fixed-mobile integration:* Digital convergence at the network layer encompasses not only fixed networks, but also promotes fixed-mobile integration, i.e., the technological integration of fixed and mobile telecommunications infrastructures as well as the bundling of respective communications services (OECD, 2015). From a supply-side perspective, increasing wireless transmission speeds and ensuing higher data volumes sent over radio interfaces require the integration of base stations into dense and high-bandwidth concentration networks (5G PPP, 2015). At the same time, consumers' demand for communications services bundles including a seamless handover between fixed and mobile services has significantly grown (Grzybowski and Liang, 2014). In consequence, the traditional technological boundaries between fixed and mobile telecommunications markets blur, which is further indicated by hybrid access products that connect to a fixed as well as a mobile access network, simultaneously (Leymann et al., 2015). In conclusion, these developments challenge the notion of delineated regulatory regimes dedicated to specific infrastructures, such as mobile and fixed networks, and ultimately suggest the necessity of *regulatory convergence* irrespective of the underlying technology. Moreover, the consolidation in the mobile telecommunications industry has effectively reduced the number of distinct infrastructures (Genakos et al., 2015). In consequence, the market structure is becoming increasingly similar to fixed telecommunications markets as noted above.

*5) Public-sector participation:* The increasing economic and societal relevance of digital services has led to direct public intervention at the network infrastructure and operations level, especially in rural less densely populated areas. In particular, consideration of spill-over effects and positive externalities, the universal service principle, and the objective to end the digital divide are cited as legitimatory reasons for those state activities (see, e.g., Gómez-Barroso and Feijóo, 2010, for an overview). If public-sector participation complements private activity, most notably in the case of state aid, the effects and trade-offs resulting from mandatory access obligations are magnified: Whereas public intervention strengthens the rationale for non-discriminatory access offers to wholesale services in order to avoid the distortion of competition, such access obligations may discourage private investments particularly in those areas where they are most required.

*6) Over-the-top communications services:* The technical decoupling and logical separation of network operations has enabled IP-based over-the-top services providers to enter communications and digital services markets without an own infrastructure. In turn, this diminishes returns for network operators from traditional revenue sources (Peitz and Valletti, 2015). Yet, at the same time, these services are the main drivers of demand for fixed and mobile access services, which however may be difficult to monetize as illustrated by objections raised in the context of net neutrality (Krämer et al., 2013). In consequence, authorities are challenged to decide whether the regulatory regime at the network access layer needs to be adjusted in light of this additional competitive pressure at the services layer in order to create a level playing field (cf. Krämer and Wohlfarth, 2015).

In consequence, these trends raise several issues with regard to the design and implementation of regulatory institutions that can safeguard OA at the network infrastructure level. In fact, these issues are currently controversially debated with regard to a realignment of the European regulatory framework (European Commission, 2016c). Whereas price regulation in retail markets has been faded out from the European Commission's (2014a) recommendation on relevant markets susceptible to ex ante regulation, price regulation of wholesale prices for physical and virtual access products remains the recommended default and the prevalent regulatory remedy in European markets up to date. However, with respect to the rollout of NGA technologies, some national regulatory authorities (NRAs) have attempted to depart from the commission's recommendation and suggested alternative regulatory regimes in lieu of cost-based access regulation. For instance, the Austrian NRA proposed wholesale access prices on the basis of a margin squeeze test (European Commission, 2013f), whereas the Spanish NRA exempted NGANs above a defined data transmission threshold from price regulation (European Commission, 2008). This latter approach may be viewed as a form of regulatory holidays, which has been proposed to resolve the truncation problem in the case of risky investment (Gans and King, 2003, 2004). Despite the concerns about insufficient investment incentives due to cost-based price regulation, the European Commission in the past has critically scrutinized and subsequently often appealed those proposals on the ground that they would contradict the harmonized regulatory framework at the EU level (see, e.g., European Commission, 2013d). Instead, European policy makers frequently argue that static and dynamic incentives are invariably aligned and reinforcing each other (see, e.g., Vestager, 2015), despite growing empirical evidence (inter alia Briglauer et al., 2013; Bacache et al., 2014; Klumpp and Su, 2015) that suggests the presence of a trade-off between static and dynamic efficiency.

Recently, several high-profile policy initiatives and legislative proposals point to an increasing willingness at the European level to rethink fundamental cornerstones of the regulatory framework as the aforementioned trends become more noticeable and urgent (Bauer, 2010; Ünver, 2015). The *Europe 2020* strategy, adopted in 2010, with its *Digital Agenda* for Europe has emphasized the need to roll out high-speed NGANs and set ambitious coverage and adoption targets (European Commission, 2010, 2014b). Thereupon, the European Commission's (2013a) recommendation on non-discrimination and costing methodologies marked the first executive action at the European level diverging from the prevalent paradigm of ex ante wholesale price regulation, as the commission explicitly enabled national regulators to replace cost-based price regulation with non-discrimination obligations. In the same year, the European Commission (2013e) presented its *Connected Continent* legislative package, which aimed at strengthening the European digital single market, offering more favorable conditions on market consolidation and suggested, among others, the transition to simplified and uniform (virtual) wholesale products across EU member states. However, the final political compromise reached in 2015 only included new rules on international mobile roaming charges and net neutrality (European Commission, 2015d), whereas the revision of regulatory rules on wholesale access was postponed (see Renda, 2015, for a commentary). The latest initiative by the European Commission (2015a), the *Digital Single Market* strategy reiterates the need for a framework aimed at strengthening investment incentives, but has so far not discussed any legislative changes in this regard (European Commission, 2015c). Yet, at the latest, the upcoming review of the European Regulatory Framework will require a reevaluation and possibly a redesign of regulatory rules on wholesale access at the European and the member states level (European Commission, 2016c).

In this context, sector-specific regulation may not be viewed and evaluated in isolation, but should be considered within the larger competition policy and antitrust framework. Most notably, recent decisions in merger control proceedings (Genakos et al., 2015) illustrate the interdependency and interaction between both frameworks with regard to the effects on competitiveness of oligopolistic markets. In particular, the decision on the allowed level of consolidation and thus the number of competitors in a market has direct ramifications on the necessity and adequacy of regulatory remedies (see, e.g., the discussion of merger consequences for the definition of regulatory markets by Bundesnetzagentur, 2015). Moreover, antitrust rules may constrain the scope of cooperative agreements among competitors, which may be conducive to investment incentives, but may also be to the detriment of competitors or consumers (Jorde and Teece, 1990; Baumol, 2001; Schellingerhout, 2011). Finally, ex ante regulatory mechanisms and ex post competition policy rules need to be aligned and applied consistently in particular with respect to the enforcement of anti-competitive conduct prosecuted under both frameworks (see, inter alia, Geradin and O'Donoghue, 2005; Hellwig, 2008).

## Trends at the digital services layer

Above all, recent policy reform initiatives in the information and communications technology (ICT) context are influenced to a large extent by the developments at higher layers of the value chain: the emergence of new digital services markets and the success of online platform business models, which in turn have allowed some of these platform operators to gain significant market power in their respective markets (Peitz and Valletti, 2015). Thus, technological progress did not only transform the infrastructure layer, but enabled the development of new services markets on top of it. In particular, the virtualization of goods through digitization together with the logical separation of the services layer from the infrastructure layer have lowered supply-side barriers to entry into services markets. Moreover, they have allowed for rapid scalability of firms' operations due to zero marginal costs, which in turn facilitate bundling of services and innovative pricing strategies (see, inter alia, Bakos and Brynjolfsson, 1999; Shampanier et al., 2007). In addition, low distribution costs allow to serve content and services at a global level and exploit substantial economies of scale. Although these factors, among others, have induced the market entry of a vast number of specialized online content and services providers and thus have significantly increased the accessible variety of goods and services for consumers globally (see, e.g., Brynjolfsson et al., 2003), network and feedback effects together with scale advantages have facilitated the emergence of a few dominant firms (see, inter alia, Evans and Schmalensee, 2009, 2013). In consequence, these firms have been characterized as new *gatekeepers* in the ICT value chain (Baye and Morgan, 2001; Ballon and Van Heesvelde, 2011). Moreover, among these firms, which have first emerged in a particular market, there is a continuing trend to expand into adjacent markets, thus creating *services ecosystems* that encompass several layers of the ICT value chain (Monopolkommission, 2015). In the light of the above-mentioned developments, several of those firms have been confronted with antitrust or regulatory scrutiny. Most notably, Alphabet (Google) with its online search and its mobile operating system Android (European Commission, 2015b, 2016a; Nicas, 2016), Amazon with its online retail store and its ebook platform (Budzinski and Köhler, 2015), as well as Facebook with its social network market (Bundeskartellamt, 2016) have been accused of abusing or leveraging their market power. At the core of these accusations, *data*, more specifically user and usage data, is often referred to as the new bottleneck resource in ICT markets (Graef et al., 2015).

Data may create economic value as the enabler of new and enhanced marketing instruments as well as a vital input factor for the creation and refinement of information services. On the one hand, data-driven business models allow for indirect monetization strategies either via two-sided pricing models, in particular advertising (see, e.g., Evans, 2008), or via price discrimination (see, e.g., Taylor, 2004; Acquisti and Varian, 2005). The exploitation of indirect network effects in the former case allows firms to offer services to consumers possibly at a zero price. Moreover, the ability to employ penetration pricing and thereby to subsidize a particular market side can accelerate the diffusion of new services and thus facilitate entry into new markets (Jiang and Sarkar, 2009). In ICT markets, where services regularly represent information goods and where quick innovation cycles are prevalent, the former ability may prove to be critical for a firms' success. On the other hand, (personal) data may represent an essential supply-side input to provide and improve digital online services (cf. Levin, 2013). For instance, online search algorithms exploit the collected data on user queries and usage traffic in order to improve the ranking of organic search results as well as the display of sponsored search advertising (cf. Newman, 2014). Moreover, *personalized customization* of services, a key differentiation parameter in digital services competition, depend directly on the available data basis and data quality (cf. Acquisti and Varian, 2005; Thirumalai and Sinha, 2013; Aguirre et al., 2015). Therefore, the access to data is viewed as a crucial factor, not only for firms to succeed in ICT markets, but also for a policy framework that reaches beyond the infrastructure level to include online markets (European Commission, 2015c). In consequence, this has reinvigorated the debate about OA, now in the context of an upstream resource deemed essential for digital (online) ICT services (see, e.g., Argenton and Prüfer, 2012). In particular, questions arise with regard to whether OA concepts should and can be transferred to the services layer, as some have already called for the regulation of OA to virtual facilities (see Krämer and Wohlfarth, 2015, for a discussion).

However, as shown above, implications drawn from the infrastructure layer may not be directly applicable to the services layer, as they differ with respect to several important economic characteristics. In particular, externalities in the context of multi-sided platforms and indirect monetization models may significantly alter competitive strategies (cf. Haucap and Heimeshoff, 2014). Thus, traditional approaches to determine market power and anti-competitive conduct, established in the context of one-sided markets, may be inadequate to assess the competitiveness of these markets and to finally judge consumer harm (Wright et al., 2004). Moreover, new incentives for cooperation may arise together with innovative sharing mechanisms with regard to data as a digital input good, that is naturally different from physical input goods, which are characterized by large sunk cost and rivalry in use. Therefore, it is a priori unclear, whether market-driven incentives may be sufficient to safeguard access to essential input goods as voluntary sharing agreements may even be agreed upon between competitors (see, e.g., Mantena and Saha, 2012). On the contrary, voluntary cooperative relationships themselves may have detrimental welfare effects for competitors and consumers (Verdier, 2013), or even for the cooperating firms themselves (see, e.g., Mantovani and Ruiz-Aliseda, 2015). Furthermore, voluntary access offers on the provider's discretion may be deemed insufficient in specific cases if non-discrimination is viewed as an essential criterion. Thus, non-discrimination or neutrality obligations, which have been discussed extensively at the interface between ICT infrastructure and services, may also be considered at the services layer (cf. Easley et al., 2015). In conclusion, these considerations indicate that at first a better understanding of the incentives and implications of access relationships at the services layer is necessary in order to evaluate the need and role for OA at this layer of the ICT value chain.

# Contents

# Chapter 1

# Introduction

CONTINUOUS innovation and ubiquitous diffusion has put information and communications technology (ICT) at the center of society and the economy of the 21st century (Brynjolfsson and Hitt, 2000; Czernich et al., 2011; Cardona et al., 2013). Numerous revolutions have been proclaimed to describe the transformations that the ICT sector itself has undergone in response to technological progress, new business models, and adjusted policy objectives (see Steinbock, 2005; Noam, 2010; Vogelstein, 2013; Kitchin, 2014; Jorgenson and Vu, 2016, for only a few examples). Induced by technological innovations, the outcomes of these processes are fundamentally shaped by firms' competitive and cooperative relationships and thus by the regulatory framework that governs these interactions. At the same time, competition, cooperation, and regulation themselves constitute the key determinants of future innovation (Dosi, 1988). In this context, *Open Access (OA)* to communications infrastructure and digital information goods, i.e., the *non-discriminatory* access to an upstream bottleneck resource, takes a central role with its direct and indirect ramifications on competition and innovation (OECD, 2013). In this regard, OA regulation may represent a major *design variable* to shape market institutions and to influence and balance trade-offs between static and dynamic effects in ICT markets (Klumpp and Su, 2010, 2015). While *digitization* has, on the one hand, significantly lowered the costs to provide access, it has, on the other hand, increased the scope and variety of potential access mechanisms. In consequence, existing OA institutions may need to be rethought and redesigned. Moreover, novel OA issues may arise in the context of newly emerging bottleneck resources and even in cases where voluntary access relationships already exist. In particular, recent technological and policy trends have fundamentally affected i) the market structure and regulatory paradigm at the infrastructure layer, where OA safeguards access to communications access networks, and ii) the evolution of digital services markets, where OA is discussed with regard to the non-discriminatory access to immaterial upstream bottleneck resources such as data or intellectual property.

The ongoing policy debates caused by the technological advancements in ICT markets highlight the interplay between technical and legal determinants on the one hand, and strategic processes and economic outcomes on the other hand. In order to *design* institutions, which can govern and shape competitive and cooperative processes according to given policy objectives (North, 1991; Roth, 2002), it is paramount to *understand*, *explain* and *predict* the incentives and trade-offs that arise in these markets (cf. Gregor, 2006). Thereby, the virtual nature of digital goods allows for a new degree of freedom with respect to the dimension, the type and the degree of possible policy interventions. In consequence, this emphasizes the need for theory-informed market design and economic engineering (cf. Gimpel et al., 2008). As goods and services themselves become *artificial* and subject to deliberate design decisions, so do the institutions that encompass them. Given the vital importance of technological and economic factors in the ICT context as well as the interactions among them, research at the interface between Information Systems (IS) and Industrial Organization (IO) is particularly suited to establish and refine robust theories that can guide the conceptualization and implementation of these design proposals together with their respective policy implications. In general, this i) requires an analysis of the incentives, externalities and trade-offs that arise from a particular design in a particular context, and ii) calls for empirical testing of theoretical predictions and prototypical evaluation of design proposals prior to implementation at large scale in practice. Whereas the first issue can be addressed by analytic models based on stylized facts and the extant theoretical body of knowledge, the second issue requires an empirical testbed that can capture behavioral effects and isolate causal relationships by controlled variation, which can be achieved by laboratory experiments. This thesis will draw on both methodologies to address the research questions outlined in the following.

## 1.1 Research questions

Across different ICT markets, this thesis examines firms' strategic incentives to provide access to an internal upstream resource and investigates the implications for competition and consumers. Therefore, this thesis focuses on conditions that facilitate voluntary access agreements, but also identifies regulatory institutions that enforce the principles of non-discriminatory access according to the core idea of OA if market mechanisms are found to fail in this respect.

At first, however, it is necessary to clarify and define what is commonly referred to as OA. Although the term has been widely used in the academic literature (e.g., Farrell and Weiser, 2003; Forzati et al., 2010) and in practice (e.g., European Commission, 2009b), varying concepts of OA have explicitly or implicitly been used and different aspects have thereby been emphasized. Therefore, a review of suggested definitions, application scenarios and the scientific literature is crucial to establish a common understanding and provide a foundation for successful implementation in practice. Moreover, a structured policy framework classifying relevant determinants of OA applications and identifying alternative regulatory OA regimes is necessary to inform the current debate about OA to next-generation access networks (NGANs) with regard to the available policy options. As policy makers and regulatory agencies are challenged to decide between alternative regulatory regimes and to design a new regulatory framework in the context of NGANs, the relevant economic trade-offs and the implications for different efficiency measures identified in the economic literature need to be made transparent in order to secure the rollout and allocation of the telecommunications infrastructure, which is deemed vital for modern economies and societies (Czernich et al., 2011). In summary, these considerations lead to the first research question:

**RESEARCH QUESTION 1.** *What defines Open Access given the definitions offered by various stakeholders in the context of telecommunications infrastructure markets? To which extent can different regulatory regimes achieve Open Access and which trade-offs arise for the decision between those regimes?*

Margin squeeze regulation (MSR) has been proposed as an alternative regulatory institution to traditional wholesale price regulation to achieve OA to an upstream resource supplied by a vertically integrated firm for independent retailers (European Commission, 2013a). Under such a regulatory regime, the wholesale price of a vertically integrated access provider may not exceed its retail price. Whereas theoretical analyses of MSR exist with regard to a single vertically integrated bottleneck supplier (e.g. Jullien et al., 2014), there is no examination of the welfare implications in the context of infrastructure competition, which is now found in many European mobile and fixed telecommunications markets, with the single notable exception of Höffler and Schmidt (2008). Therefore, it is unclear whether MSR can safeguard competitors and consumers against foreclosure of independent retailers that rely on the access to the upstream good. Given its relevance as an ex ante regulatory remedy as well as a stand-alone antitrust abuse in ex post competition law, a further empirical evaluation of theoretical predictions seems warranted in order to attain robust findings over and beyond analytic models. Next to its application in the case of infrastructure competition with a single access provider, welfare implications of MSR may change under wholesale competition, which is the case in most European mobile telecommunications markets. Yet, no study has investigated MSR in the context of wholesale competition. Thus, the second research question asks:

**RESEARCH QUESTION 2.** *What are the welfare implications of margin squeeze regulation in the presence of several independent infrastructures that may allow for competition at the wholesale level in addition to competition at the retail level?*

More generally, the emergence of infrastructure competition in many fixed telecommunications markets challenges the traditional legitimation for wholesale regulation in principle as the bottleneck resource is in fact no longer essential (Renda, 2010). Moreover, theoretical studies show that wholesale competition in the case of two distinct infrastructures can lead to competitive outcomes in wholesale and retail markets, although monopoly-like outcomes may emerge in specific cases (Bourreau et al., 2011). Therefore, the presence of duopolistic wholesale competition may be sufficient to ensure OA. However, empirical studies show that tacit collusion, which is so far not considered in the theoretical studies on wholesale competition, can significantly alter market outcomes in oligopolies with few competitors. Thus, a controlled empirical evaluation of the effects of wholesale competition is warranted to test whether it can effectively sustain competitive retail markets. Moreover, this calls for a theoretical analysis of vertically integrated firms' incentives to tacitly coordinate in upstream and downstream markets (Nocke and White, 2007; Normann, 2009). With regard to these issues the third research question considers:

**RESEARCH QUESTION 3.** *Given infrastructure competition, is wholesale competition sufficient to ensure Open Access for downstream retailers? Does wholesale competition benefit consumers?*

In the context of recent merger cases in the mobile telecommunications industry, competition authorities have repeatedly been confronted with the decision whether potential efficiency gains, due to consolidation, outweigh diminished competitiveness, due to a lower number of firms in the market. More specifically, there is the concern that implicit cooperation among competitors in the form of tacit collusion may be facilitated with fewer firms and thus competitiveness could be aggravated over and beyond the concentration of market power. Thus, an evaluation of anti-competitive effects seems of particular relevance if market concentration is reduced from four to three or even from three to two competitors. However, the detection of tacit collusion based on field data is generally difficult, because precise information on the cost structure is often missing. Yet, it is even more difficult in merger control proceedings where hypothetical counterfactuals have to be estimated and assessed ex ante. Therefore, economic laboratory experiments are well suited to empirically examine the systematic effects on tacit collusion in a controlled environment. Although, it is often assumed that there is a strictly monotonically decreasing relationship between the number of firms and the competitiveness of a market (see, e.g., Potters and Suetens, 2013), a systematic evaluation of number effects that also controls for different competition models is missing so far. Moreover, the studies which examine number effects in more specific contexts (see, e.g., Huck et al., 2004b, for homogeneous Cournot competition) do not distinguish between behavioral effects, i.e., tacit collusion, and structural effects, i.e., equilibrium predictions. Finally, there is no experimental analysis that extends the examination of number effects in the context of symmetric firms to markets with asymmetric distribution of market power. Yet, this scenario is particularly relevant in cases where incumbent operators remain in a dominant position, but competing operators have established significant market shares such that regulatory agencies consider (partial) deregulation (see, e.g., Ofcom, 2014; Bundesnetzagentur, 2015, for discussions of number effects in a regulatory context). In essence, the fourth research question reads:

**RESEARCH QUESTION 4.** *What is the relationship between the number of competitors and the competitiveness of an oligopolistic market?*

Economic laboratory experiments concerned with competitive settings and firms' strategies have traditionally been conducted in discrete time, i.e., either as a simultaneous-move or a sequential-move game. However, fixing the timing of decisions according to a pre-specified order abstracts from an important dimension of strategic decision making in practice: the decision on the timing of an action. Recently, studies have employed experimental designs with a continuous time framework, among others, in the context of a prisoner's dilemma game (Bigoni et al., 2015; Friedman and Oprea, 2012), in a network formation game (Berninghaus et al., 2006, 2007) and in a Hotelling (1929) location model (Kephart and Friedman, 2015; Kephart and Rose, 2015). A continuous time framework endogenizes timing decisions in the laboratory experiments and thus extends subjects' action space by allowing for asynchronous interactions. Experimental design in continuous time may be deemed more realistic for particular scenarios and thus may increase external validity of experimental results. Moreover, continuous time may encourage exploration of the action space as restrictions on the number of decisions are lifted and also allows for shorter feedback cycles. Yet, the effects of a continuous time framework relative to discrete time have not been investigated in the context of oligopoly competition. The following research question addresses these methodological considerations:

**RESEARCH QUESTION 5.** *Does continuous time in experiments on oligopoly competition facilitate tacit collusion relative to discrete time?*

In digital services markets, the upstream resource to which (open) access may be granted is represented rather by virtual goods, such as data, intellectual property or algorithms than by physical infrastructure (see, e.g., Easley et al., 2015; Krämer and Wohlfarth, 2015). Current antitrust cases that center around online intermediaries and their alleged market power on the basis of unique data sets and the ensuing information advantage exemplify the value that is attributed to these resources (Argenton and Prüfer, 2012). Yet, there also exist voluntary access relationships and agreements among competitors (Mantena and Saha, 2012; Mantovani and Ruiz-Aliseda, 2015). In particular, *social logins*, such as "Log in with Facebook", enable the respective social network and the content providers to share data, which individually improves their ability to place targeted advertising. Whereas these mechanisms can improve a website's user experience and therefore enjoy great popularity among content providers and users alike in practice, it is a priori unclear how these collaborative efforts impact the competition between content providers. In particular, data sharing may affect competition between special-interest content providers from the same domain with regard to users' choice to visit the respective platform but also between a general-interest content provider (the social network) and those content providers with regard to the display of advertising. Therefore, a theoretical microfoundation that relates the effects of data collection and the ability to target users to ensuing advertising profits in the context of competing outlets is required. Moreover, with regard to (data) neutrality considerations it is unknown whether voluntary agreements are sufficient to ultimately maximize users' benefits. The sixth research question summarizes these issues as follows:

**Research Question 6.** *What are the competitive effects of social logins that allow for reciprocal access to user and usage data among online content providers?*

## 1.2 Structure of this thesis

The remainder of this thesis addresses the above research questions and is organized as follows. Chapter 2 provides an introduction to the concept of Open Access in the context of the current transition to next-generation access networks at the telecommunications infrastructure layer.[1] Addressing Research Question 1, the chapter attempts to reconcile the diverse views on OA by offering a definition and a conceptual framework by which OA endeavors can be identified and uniquely classified. Along this framework, the extant economic literature is surveyed with regard to aspects of competition and social welfare, investment and innovation, as well as practical and legal issues. Based on these insights, a policy guideline is developed that may assist policy makers in identifying the appropriate OA scenario for the regulation of telecommunications infrastructure.

The methodological foundations of this thesis are laid out in Chapter 3.[2] Based on the proposal of an idealized research process cycle for microeconomically founded IS research, it is argued how theoretical and empirical research approaches may be employed to develop and refine robust theory. Building on this framework, it is argued how analytic models and laboratory experiments can be combined to serve as a testbed for regulatory design proposals. Finally, Research Question 5 is investigated by an experimental study that compares oligopolistic competition under continuous and discrete time.

Chapter 4 addresses Research Question 2 and considers a game-theoretic model of margin squeeze regulation in a market with horizontally differentiated competition be-

[1] Chapter 2 is based on joint work with Jan Krämer (Krämer and Schnurr, 2014).
[2] Section 3.1 is based on joint work with Jan Krämer (Krämer and Schnurr, 2016). Section 3.3 is based on joint work with Niklas Horstmann and Jan Krämer (Horstmann et al., 2015).

tween two vertically integrated firms and one non-integrated retailer, whereby the non-integrated firm relies on wholesale access provided by one of the integrated firms.[3]

On the basis of the methodological foundations set out in Chapter 3 and the theoretical analysis in Chapter 4, Research Questions 2 and 3 are examined empirically in Chapter 5.[4] More specifically, Chapter 5 employs a continuous time economic laboratory experiment with both student and expert participants to compare market outcomes under different modes of wholesale competition as well as under an OA regulation preventing a margin squeeze. A theoretical explanation for the obtained experimental results is provided based on a comparative analysis of collusion incentives among vertically integrated firms in the cases of a wholesale monopoly and wholesale competition.

Next, Chapter 6 conducts a meta-analysis of the literature on oligopoly experiments and two economic laboratory experiments to address Research Question 4.[5] Therefore, the number of firms as well as the mode of competition are systematically varied in an experimental analysis of symmetric firms. Furthermore, number effects between three and four firms are examined for asymmetric distributions of market power.

Chapter 7 focuses on voluntary access relationships at the services layer of the ICT value chain and addresses Research Question 6.[6] Therefore, content providers' strategic decisions whether to offer and/or adopt a social login are scrutinized and feasible market outcomes are identified. Thus, the incentives and fundamental trade-offs that drive adoption decisions and impact the profitability of content providers are examined based on a stylized model of horizontal competition between special-interest content providers, and advertising competition between special-interest content providers and the general-interest content providers.

Finally, Chapter 8 concludes and discusses limitations of this thesis together with promising avenues for future research.

[3]Chapter 4 is based on joint work with Niklas Horstmann and Jan Krämer (Horstmann et al., 2016a).
[4]Chapter 5 is based on joint work with Niklas Horstmann and Jan Krämer (Horstmann et al., 2016c).
[5]Chapter 6 is based on joint work with Niklas Horstmann and Jan Krämer (Horstmann et al., 2016b).
[6]Chapter 7 is based on joint work with Jan Krämer and Michael Wohlfarth (Krämer et al., 2016).

# Chapter 2

# A Unified Framework for Open Access Regulation

WITH the Digital Agenda 2020 the European Commission has set ambitious targets for its member states and the European telecommunications industry. The requirements stipulate that until 2020 every household in the European Union (EU) should be covered by a broadband connection offering at least 30 Mbit/s of bandwidth. Moreover, a penetration rate of above 50% is envisioned for 100 Mbit/s connections. In contrast to the ambitious political goals, the implementation status is far behind schedule. For instance, by mid 2013 only 2% of European households have already subscribed to a connection offering 100 Mbit/s or more (European Commission, 2013b). Thus, large investments are needed to upgrade the existing broadband networks to the desired level. Especially, the deployment of NGANs represents the most substantial share of these investments.

At the same time, European network operators experience declining revenues and profits facing strong competition by alternative infrastructures and Internet Protocol (IP)-based services. In particular, former incumbent operators have criticized the current regulatory regime as heavy-handed and hostile to any investment strategy, portraying

This chapter is based on joint work with Jan Krämer (Krämer and Schnurr, 2014).

the European regulatory framework as the underlying root cause for the industry's bad performance (ETNO, 2013).

In July 2012, Commissioner Neelie Kroes announced her plan to enhance the broadband investment environment signaling her willingness to lighten the regulatory burden. The industry and various analysts have viewed this promise as a paradigm shift of the European Commission's stance towards access regulation. While it will likely not lead to a complete withdrawal of the regulatory framework, the balance between static and dynamic efficiency goals is going to be readjusted. Addressing the slow uptake of next-generation networks in Europe compared to Asian countries and the US, Kroes declared establishing an investment-friendly environment as the primary goal. While only a year before, the Commission postulated strict unbundling rules based on cost-based pricing, Kroes now advocated in favor of an approach based on non-discrimination rules. In addition, she promised to abstain from further price cuts of wholesale access charges to legacy copper networks and to establish a harmonized stable price floor across Europe (Kroes, 2012).

The first action of the European Commission in light of this announcement is the recommendation on non-discrimination and costing methodologies, which was published in September 2013. The recommendation outlines the conditions that would allow European regulators to replace cost-based price regulation with non-discrimination obligations, even in the presence of significant market power (European Commission, 2013a). During the consultation process that followed the draft recommendation, discussions have evolved around the implementation of non-discrimination. Most of all, contrary views have been stated on what actually defines a level playing field between the incumbent's subsidiary and competitors, besides a uniform wholesale price. In particular, network operators oppose an *equivalence of input* regime, that prescribes equality in terms of the used infrastructure and processes. Instead they argue in favor of *equivalence of output* that abstracts from the actual infrastructure and is concerned with equal functionality. Thus, the debate illustrates the difficulties and conflicts that are hidden behind the intuitive notion of non-discrimination.

Previously, in Europe the idea of non-discriminatory access has been discussed under the notion of Open Access and in the context of public-sector participation (European Commission, 2009b). It has frequently been stated that OA could provide a balance between static and dynamic efficiency (e.g., Klumpp and Su, 2010; OECD, 2013). Yet, OA has been used to describe a very diverse set of access concepts. While there is no explicit definition given by regulators or legislators, the term has been used in various contexts of access regulation, state aid and voluntary provision of wholesale access provision. Despite the widespread use, there is no common understanding of the term among scholars, regulators and industry practitioners. Therefore, a clarification of the actual OA notion and the related concept of non-discrimination is needed. In particular, a structured evaluation of the diverse applications is required in order to allow for precise policy conclusions that can guide the search for a new European regulatory framework.

With regard to this ongoing discussion, this chapter is concerned with the application of OA at the network infrastructure level as well as with current regulatory issues and use cases that have influenced the European debate. At the same time, the history of OA as a regulatory remedy goes back for several decades and encompasses applications in telecommunications, but also in other industries such as the media sector. Policy debates about appropriate access provisions within the US have coined and significantly shaped the understanding of the OA principle. While covering the details of these historic applications is beyond the scope of this study, information drawn from the US is included when it can be applied to and interpreted in the European NGAN context. Moreover, this chapter does not explicitly address the net neutrality controversy (which is, e.g., surveyed by Krämer et al., 2013) nor a comparison of both concepts (which is, e.g., discussed by Hogendorn, 2007). However, the proposed framework may serve as the basis for further refinements and extensions that focus particularly on quality of service (QoS) characteristics and requirements in access relationships among network operators as well as between network operators and application services providers. On top of the telecommunications network infrastructure, digital convergence is likely to raise new questions whether traditional network concepts should be applied to higher layers of the value chain. Therefore, the discussion at the end of this chapter points to potential applications of OA at the services level of the ICT value chain.

Along these lines, the remainder of this chapter is structured as follows: In Section 2.1 the various notions of OA that were proposed by different stakeholders are presented and subsequently reconciled into a unified definition. Moreover, a conceptual framework is developed that allows for the classification of the diverse OA application scenarios. Based on this classification, in Section 2.2 the extant economic literature is reviewed and policy implications are derived for each OA application scenario. Section 2.3 relates the various OA applications to each other and presents an overreaching policy guideline for the OA regulation of NGAN. Finally, Section 2.4 discusses the main results and identifies possible limitations and extensions.

## 2.1 The concept of Open Access

There is a fundamental lack in common understanding what actually defines an OA policy and along which dimensions OA regulation can be structured. For example, while OA has been used to describe access obligations including price regulation in the US (Speta, 2000; Farrell and Weiser, 2003), the European Commission's understanding of OA refers to mandated access in the case of state aid (European Commission, 2013c), and on the other end network operators have put emphasis on voluntary access (Deutsche Telekom, 2011).

In the following, the definitions of OA proposed by the European Commission, the German telecommunications industry, and proponents of the open access network model are presented. The definitions indicate that there is common ground in referring to non-discrimination as the central criterion, but they also illustrate that stakeholders highlight different additional aspects. As mentioned above, these aspects differ with respect to how open access terms shall be reached (mandated or voluntary), but also with respect to which access levels of the value chain are concerned and whether the notion of OA requires a specific organizational form of the access provider (vertical separation, public-sector participation).

### 2.1.1 Open Access in the context of public-sector participation

The emphasis on the European context is founded in the European Commission's use of the actual term in the State Aid Guidelines in 2009, thus introducing OA as a legal criterion that European network operators have to fulfill when they receive state aid (European Commission, 2009b). Since the European Commission has refrained from giving an explicit legal definition, various stakeholders have subsequently engaged in interpretations and new definitions of the term, in particular in the context of public-sector participation, but also with regard to a potentially larger application scope.

The implicit definition that can be derived from the State Aid Guidelines is summarized by the Body of European Regulators for Electronic Communications (BEREC, 2011, p.8):

> "The term 'open access' [...] refers to mandated wholesale access whereby operators are offered effective, transparent and non-discriminatory wholesale-access to the subsidized network(s)."

The notion of non-discrimination is defined in Article 10 of the European Access Directive and requires equality between the integrated downstream subsidiary and an independent retailer as well as between two independent retailers (European Commission, 2002). However, this does not prohibit differentiated access offers in general. In particular, different prices can be charged if this differentiation is based on objectively justifiable reasons. The recommendation on non-discrimination explicitly mentions that volume discounts and/or long-term access pricing can be compatible with the non-discrimination criterion (European Commission, 2013a). In order to safeguard effective implementation in the context of such volume discounts, the recommendation stipulates that favorable conditions to the subsidiary are not allowed to exceed the highest discount offered to independent downstream firms.

In the US context, OA has been mentioned, on the one hand, in association with state-owned municipal networks (Lehr et al., 2004), where OA was seen as an instrument to ensure non-discriminatory access and may be adopted voluntarily or mandated. On the other hand, OA has frequently been used interchangeably with mandated price-regulation (Speta, 2000).

### 2.1.2 Voluntary Open Access

In Germany, OA has played a prominent role in the debate about potential regulatory regimes governing NGANs. In the context of regional deployment of NGA networks and in the advent of new business models, OA has been seen as a solution to drive rapid construction, fast penetration and interoperability. The Federal Network Agency, Germany's national regulatory authority (NRA), established the "NGA-Forum" with the goal to promote the standardization of access products which it views as a prerequisite for symmetric OA. In contrast to the European Commission, which has characterized OA as mandated wholesale access, network operators here have tried to establish OA as a concept that relies on the voluntary decision by the particular access provider. A definition representing the consensus among network operators was presented at the German IT-Summit (2010, p.4):

> "Open Access in FTTB/FTTH-Networks refers to the voluntary, non-discriminatory access at different levels of the value chain."

### 2.1.3 The Open Access network model

Already prior to the State Aid Guidelines, a strand of literature emerged based on a notion of OA which not only requires non-discrimination, but also functional separation between network operators and the services companies. The OA network model is hereby characterized by the separation of roles between the service provider and the network owner. Battiti et al. (2005) stipulate the belief that vertical integration of communication networks is the main reason for "high costs of services and barriers of competition" (p.1). While a further economic analysis or elaborated reasoning to back the hypothesis of hindered innovation due to vertical integration is often neglected, proponents instead point to public infrastructure such as roads in the case of transportation as a proven benchmark. In their view, a concept relying on mutual control and shared usage of physical access networks is able to lower costs for deployment and usage of access networks, while providing users with a greater choice and service providers with more freedom (Battiti et al., 2005). This line of argument focuses rather on aspects of static efficiency of network operations, e.g., fair competition among service providers, than aspects of dynamic efficiency as actual investment for building networks is believed to be facilitated by technological innovation, e.g., wireless networks (Bogliolo, 2009). A summarizing definition of OA as viewed by this strand of the literature is given by Forzati et al. (2010, p.1):

> "In the open access network model, the roles of the service provider and the network owner are separated, and the service providers get access to network and the end customers on fair and non-discriminatory conditions."

As can be seen by the manifold definitions, the criterion of non-discrimination is central to the concept of OA. However, there is a diverse understanding among stakeholders of how the goal of non-discriminatory access is effectively and efficiently achieved. Therefore, the definitions differ according to the requirements they postulate and whether OA should be established as a voluntary or regulated regime.

Based on these insights the following unifying definition is proposed:

**Definition 2.1** (Open Access Regulation)**.** *Open Access regulation refers to the mandated or voluntary provision of access to an upstream resource which must be based on the principle of non-discrimination. The concept may apply to publicly or privately owned access providers* *that are vertically separated, integrated or represent a cooperative of multiple entities. Open Access regulation usually refers to the network layer, but may also be applied to other layers of the telecommunications value chain.*

Considering this definition, it becomes clear that non-discrimination may be achieved by various approaches. In fact, even price-regulation can be included as a specific version of mandated OA that attempts to implement non-discrimination by setting a regulated access charge. In the narrow sense, however, Open Access refers to *mandated non-discrimination*, where the upstream provider may freely set the terms of access, but is forced to provide access on a non-discriminatory basis. Thus, following the previous discussion, the proposed definition also reconciles the different meanings of OA in Europe and the US. As a consequence, scholars analyzing OA have to be aware of the large scope that the concept actually comprises and derived implications need to be explicitly related to a particular application of OA.

### 2.1.4 A conceptual Open Access framework

In order to allow for the classification of results obtained by the extant economic literature and in order to be able to derive coherent policy conclusions, a conceptual framework is offered that structures the further analysis of particular OA relationships and allows for a subsequent comparison of different OA models. The OA classification framework (Figure 2.1) is based on three dimensions that are deduced from the key characteristics of the presented definitions and represent the major determinants of access relationships in the NGAN context.

The *vertical structure* denotes how ownership in the access network (the upstream market) and activities in the services market (the downstream market) are related. Of course, the actual degree of integration may not only be defined by common ownership, but also by additional dimensions such as task integration, knowledge integration and coordination integration (Jaspers and van den Ende, 2006). While being aware of the fine-granular spectrum of vertical organization models, the subsequent analysis is structured by referring to the most relevant cases, i.e., i) an integrated firm that is also active in the downstream market, ii) a separated wholesaler, or iii) a cooperative undertaking between several downstream competitors (co-investment).

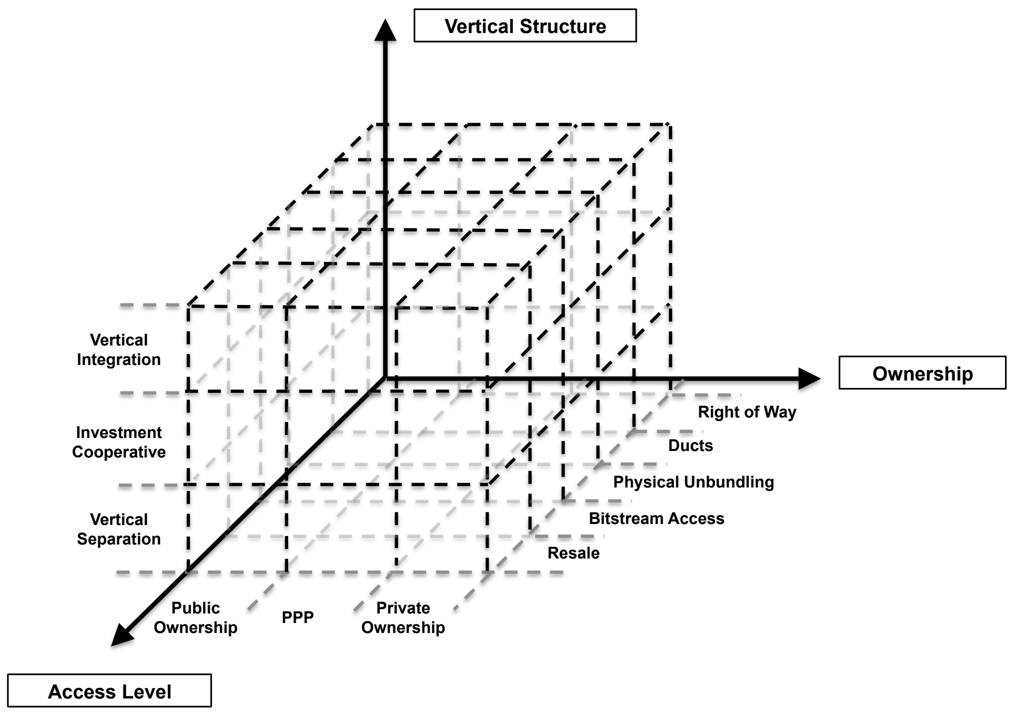
*Ownership* denotes the ownership structure and the goals of the access provider that vary with the influence of the public sector. The access provider may be entirely state-owned, as in the case of municipal public utilities or public access networks (e.g., the Australian National Broadband Network), represent a public-private-partnership (PPP) or a private-sector, profit-oriented corporation. PPP models again can be differentiated according to the allocation of responsibilities concerning financing, design, construction and operation of the access network (European Commission, 2011). The goals of the organization according to its ownership structure may range from pure profit-maximization to non-profit pursuit of public interests. A further differentiation may be needed in the case of a private network operator specifying whether the firm is subject to price-regulation or whether it is unconstrained in setting its wholesale prices.

The *access level*, finally, indicates at which level of the value chain access is given to downstream competitors. In this vein, the concept is readily applicable to a wide and diverse set of access relationships. Since the emphasis of this article is on NGANs, the following analysis is particularly concerned with access levels to “Internet infrastructure services", i.e., Open Systems Interconnection (OSI) layers one through three, according to the terminology introduced by Jordan (2009). While most incentive-based arguments concerning vertical integration and public ownership apply equally to higher levels of the Internet value chain, specific characteristics of “Internet application services" (Jordan, 2009) need to be considered in addition.[1] The set of feasible access options to network facilities may differ across access technologies (e.g., coaxial, copper, fiber networks) and depend as well on the network architecture (e.g., point-to-point and point-to-multipoint). Access may also be granted at different geographical locations. Moreover, the introduction of QoS and respective traffic classes may increase the technical and commercial possibilities of further differentiation in access agreements

[1]Section 2.4 discusses how the framework can also be applied to higher access levels. Chapter 7 presents an analysis of voluntary (open) access to user and usage data in online content markets.

between network operators. Eventually, the access level defines the degree of control and the potential quality differentiation that the access seeker can achieve. Therefore, this dimension reflects also a well-known concept in telecommunications regulation: the *Ladder of Investment* (Cave and Vogelsang, 2003; Cave, 2006a). Figure 2.1 illustrates potential access levels in the case of a fixed NGAN. A more elaborate discussion of the Internet layers as well as architectural principles can be found in van Schewick (2010). Claffy and Clark (2013) point to a further important differentiation when considering access to (infrastructure) platforms in convergent networks, namely the distinction of the platform's intended use (closed vs. open to complementors) and its construction (single- vs. multi-firm formation). Thus, their framework is especially suited to guide consistent regulation of emerging *specialized* or *managed services* and coexisting open systems like the Internet that are based on identical physical networks.

FIGURE 2.1: *OA classification framework: vertical structure (impact on downstream market), ownership (goal of organization), and access level (quality differentiation).*




Based on these three dimensions bilateral access relationship can be characterized, but also more complex ventures (as, e.g., proposed by Forzati et al., 2010) can be illustrated by displaying the distinct and potentially heterogeneous individual relationships. Note, however, that access relationships are primarily defined by the vertical structure and the ownership, whereas the access level defines the spectrum of this particular relationship. Therefore, it is sufficient to consider the dimensions of vertical structure and ownership to distinguish four general settings of potential OA applications (as illustrated by Figure 2.2).

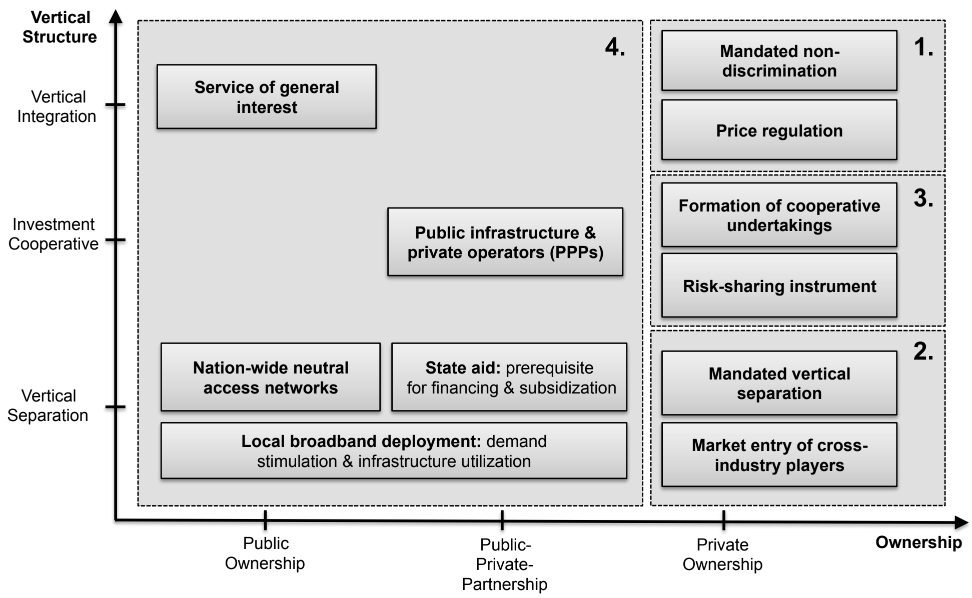
1. **Vertically integrated network and services providers** that are typically represented by national incumbents or regional operators of NGANs. In this context, an obligation to provide non-discriminatory access may be seen as an alternative instrument to cost-based price regulation. Further discussions have evolved around the question whether OA could be realized as a voluntary concept.

2. **Vertically separated, profit-maximizing network operators** including organizations that were established by vertical separation of formerly integrated operators (e.g., Openreach in the UK ) and cross-industry entry of companies that are active in other markets such as energy utilities (e.g., RWE Germany). OA is envisioned to stimulate wholesale agreements by means of transparency and standardization resulting as a consequence of the non-discrimination condition.

3. **Cooperative undertakings by private-sector organizations** including risk- and network-sharing contracts as well as agreements on geographically complementary investments. Here, OA may serve as a regulatory tool to govern ex-ante access to the cooperative or ex-post access to the network.

4. **Public-sector participation** including local and nation-wide initiatives, state aid, public outsourcing, and public-private joint-ventures where the physical network is designed, built and maintained by the public entity while private firms operate the active network facilities and provide services. In this context OA is usually seen as an instrument to minimize the distortion of competition by state activity and is in general stipulated as a mandatory obligation.

FIGURE 2.2: *Classification of OA application scenarios.*




## 2.2 Literature survey

Based on the preceding classification, each of the identified OA applications is assessed from an economic perspective. To this end, implications for each of the respective forms of vertical structure and ownership are derived by surveying the extant economic literature. A particular emphasis is put on the presentation of the prevailing effects that have been identified by scholars as determinants of static and dynamic efficiency. In addition, regulatory and legal aspects that follow from particular characteristics of the access provider are noted. More precisely, the following list comprises the set of efficiency measures and determinants that are used throughout the assessment:

- *Static efficiency* is measured by social welfare and constituted by allocative and productive efficiency. Relevant determinants include the presence of transaction costs, economies of scale and scope, price and non-price discrimination, foreclosure, intensity of competition, and externalities.

- *Dynamic efficiency* encompasses technological progress and innovation, i.e., improvements in productive efficiency, which can be measured by social welfare over time (Kolasky and Dick, 2003; Viscusi et al., 2005). The literature on telecommunications has employed several proxies in order to quantify dynamic efficiency, such as the magnitude of investments, coverage, innovation, or the extent of infrastructure-based competition. In vertically related industries these outcomes are affected by the degree of coordination between upstream and downstream segment, and by the prevailing investment incentives of the incumbent as well as potential entrants.

- *Regulatory and legal requirements* describe the necessary degree of information and monitoring capability, accountability, task complexity and effectiveness.

### 2.2.1 Vertical integration and separation of the access provider

Liberalization in the telecommunications sector was driven by the perception that telephony service and long-distance networks could potentially be served by multiple competing firms. In contrast, the access network was still seen as a natural monopoly by the consensus opinion. Accordingly, questions concerning vertical separation have mostly been analyzed by assuming a monopolistic supplier that serves an oligopolistic or competitive downstream market. Addressing doubts about the natural monopoly assumption due to new access technologies (mobile, fixed-wireless), the recent literature on investment and regulation (see, e.g., Vareda, 2011) and on price discrimination (Inderst and Valletti, 2009) has extended the conventional model by allowing for potential replication of the upstream resource through market entry.

In general, the literature can further be distinguished according to whether the upstream firm possesses freedom in setting wholesale prices or if prices are set by the regulator. Particularly, the impact of price regulation on investment incentives has been thoroughly analyzed by a recent strand of literature. The results and remaining research questions of this literature are covered in a survey by Cambini and Jiang (2009), and therefore, they are not included in this overview. Further summaries that deal with specific aspects of the vertical structure in the telecommunications industry can be found in Tropina et al. (2010), Janssen and Mendys-Kamphorst (2008), Gonçalves and Nascimento (2010), and Yoo (2002).

Riordan (2008) presents a summary of the major theories explaining benefits and weaknesses of vertical integration in terms of static efficiency. It is shown that the perception about vertical integration as a beneficial or worrying practice has changed repeatedly since the 1950s according to the predominant theory at a particular epoche. Major insights have been obtained by the structure-conduct-performance theory dealing with vertical foreclosure and leverage of market power, the Chicago School stipulating the theories of single monopoly profit and elimination of price markups (Spengler, 1950), Transaction Cost Economics developing the theory of incomplete contracts (Whinston, 2003), and Post-Chicago Economics by pointing out to incentives on restoring monopoly power (Rey and Tirole, 2007b).

The general question what actually determines firms' boundaries and the degree of vertical integration is adressed in the first part of an extensive review by Lafontaine and Slade (2007). The authors present the most prominent theories along with prototypical analytical models and investigate whether derived predictions are supported by empirical findings. First, there is strong empirical support for the hypotheses derived from Transaction Cost Economics with regard to backward-integration. High asset specificity, transaction complexity and uncertainty are identified as drivers of integration between suppliers and manufacturers. Second, moral-hazard arguments established by agency theory seem to explain forward-integration between manufacturers and retailers very well, with the exception of the empirically observed negative relationship between downstream risk and vertical integration. The second part of the survey summarizes the observations made by the empirical literature which has studied the effects of vertical integration on firms' performance and on consumer surplus. The obtained conclusions are included separately hereafter in order to relate the empirical findings to the respective underlying theoretical concept.

**The Single Monopoly Profit Theorem (SMPT)** The theorem stipulates that an upstream monopolist will generally not inefficiently leverage its market power to complementary or downstream markets since it can generate the monopoly profit only once. Due to the incentive to maximize output of the complementary downstream products, the monopolist will decide to integrate forward only in the case if the downstream market is inefficient. However, this conclusion is subject to a number of exceptions as presented by Farrell and Weiser (2003) and builds on the following assumptions. First, the monopolist must have the ability to make enforceable multilateral commitments as shown by the theory of *restoring monopoly power* (Rey and Tirole, 2007b). Second, the monopolist must posses sufficient freedom to set wholesale charges in order to extract the monopoly rent. This is prohibited by most regulatory regimes that implement price regulation on a cost basis. In fact, it is the goal of regulated industries to prevent the monopoly profit in the first place. Moreover, the SMPT fails if the upstream monopoly is under threat itself by potential "two-level entry" and may be protected by foreclosing the downstream market.

**Restoring monopoly power** Rey and Tirole (2007b) show that the ability by a monopolistic supplier to fully extract the monopoly profit breaks down if the wholesale firm is unable to commit to multilateral contracts. The monopolist has an incentive to offer a lower marginal access price to at least one downstream firm while taking a higher fixed premium. The downstream firm will accept the deal if the competitive advantage of the lower input price outweighs the additional fixed cost. Since downstream competitors anticipate this incentive to discriminate, the supplier is unable to set the monopoly price in the first place. The network infrastructure, therefore, exhibits characteristics of a durable good (Coase, 1972). The commitment problem can be resolved and monopoly power can be restored by the supplier entering the downstream market through an own subsidiary. Alternatively, the separated monopolist may circumvent the commitment problem by negotiating an exclusive agreement with one of the downstream firms. Paradoxically, monopoly power may also be restored by regulatory activity. Rey and Tirole (2007b) show that a non-discrimination criterion (other than a most-favored-customer clause) will prohibit the supplier from providing preferential treatment to a downstream firm and bind the supplier to the uniform (monopolistic) access charge.

**Raising rivals' costs (RRC)** Critics of vertical integration have frequently raised the concern that a monopolistic supplier that is active in the upstream and downstream market has an incentive to distort downstream competition by raising rivals' costs. An assessment of this anti-competitive behavior has first been conducted by the seminal work of Salop and Scheffman (1983, 1987) and was followed by extensive analysis of RRC in the context of specific characteristics of network industries. In general, the integrated firm is able to raise costs either directly via the access charge (price discrimination) or through sabotage in the process of providing the input good (non-price discrimination). The former approach differs from the latter by the additional direct income effect for the upstream firm due to a higher wholesale price. In both cases the integrated firm may benefit from a competitive advantage in the downstream market derived from lower marginal costs. At the same time, decreasing market shares of independent retailers will lead to a diminished wholesale profit. Therefore, the decision to raise rivals' costs is always associated with a trade-off between upstream and downstream profits. In general, the empirical evidence with respect to observed foreclosure and RRC behavior according to Lafontaine and Slade (2007) is mixed, but there are several studies that uncover evidence of foreclosure in the case of industries characterized by natural monopolies, most notably in Cable TV. However, several studies point to the fact that efficiency gains due to vertical integration may outweigh the costs of foreclosure and could therefore benefit consumers through lower prices.

**Price discrimination** Assessing the incentives and welfare implications of price discrimination in the case of a regulated upstream market, Vickers (1995) shows that the integrated firm has an anti-competitive incentive to favor its subsidiary. Since entry in the downstream market is assumed to be costly in terms of duplication costs, it is concluded that price discrimination may also have a positive effect on total welfare by reducing inefficient entry. Likewise, Reitzes and Woroch (2009) find that the integrated input monopolist will engage in price discrimination against downstream rivals. However, the integrated monopolist may also set an input price above marginal cost to its downstream affiliate.

For an unregulated industry, the ability to discriminate in wholesale prices leads to contrary results depending on whether upstream firm faces the threat of demand-side substitution. DeGraba (1990) shows that under the assumption of an unconstrained monopolist, the more efficient downstream firm is optimally charged higher input prices. However, with respect to dynamic efficiency a ban of price discrimination increases investment incentives of retail firms. When introducing the possibility for demand-side substitution these results are reversed (Inderst and Valletti, 2009). In particular, more efficient firms receive a discount compared to their less efficient competitors. Thereby, price discrimination hurts consumers in the short-run, but improves investment incentives, thus creating long-run benefits.

**Non-price discrimination** The literature on sabotage distinguishes between cost raising strategies that increase rivals' per-unit costs on top of the wholesale rental charge, and degradation of quality that lowers the demand of downstream competitors (Brito et al., 2012). Under a linear demand structure cost-raising and demand-reducing sabotage are indistinguishable (Reitzes and Woroch, 2009). Examples of non-price discrimination include poor quality of interconnection, delay in processing orders, creation of incompatibility, bundling of complements (Economides, 1998), or preferential treatment of affiliated content (Brito et al., 2012).

Incentives for sabotage emerge only in the presence of binding input price regulation (Beard et al., 2001; Reitzes and Woroch, 2009) and in the case that downstream firms can reap profits, i.e., that the downstream market is not perfectly competitive (Mandy, 2000). If prices are regulated, the input monopolist has to weigh higher downstream profits against lost upstream earnings when deciding whether to engage in non-price discrimination. While raising rivals' cost will lead to an increase in downstream prices and higher output by the integrated affiliate, the reduced market share of independents will reduce the demand for input (Economides, 1998). The theoretical literature has shown that while in most cases the integrated firm has an incentive to discriminate, there are exceptions in particular settings.

The results of the many theoretical models developed by scholars differ according to some key modelling decisions and assumptions about the market structure. As summarized by Mandy (2000), the incentive to discriminate is altered by the downstream market structure (degree of product differentiation, costs of sabotage to the perpetrator, presence of scale economies, relative efficiency of competitors, competition intensity), characteristics of the upstream segment (upstream margin, potential upstream competition), and the model of the integrated firm (separated or common profit maximization). Some key results are highlighted in the following.

Economides (1998) stipulates that the sum of the three described income effects incurred by non-price discrimination is generally positive, and that the monopolist raises costs until competitors are forced out of business. According to this model, the result remains unaffected by a cost advantage or disadvantage of the monopolist's subsidiary compared to independent downstream firms.

Mandy (2000) concludes that the integrated monopolist abstains from sabotage if a) the downstream market is competitive (low degree of double marginalization), b) there is a sufficient upstream profit margin, and c) the monopolist's subsidiary is substantially less efficient compared to its competitors. Referring to the latter aspect, Weisman and Kang (2001) highlight that the incentive to discriminate is most pronounced in the situation where integration is highly efficient. Thus, the regulator is presented with the challenge to choose between productive and allocative efficiency. Symmetric considerations hold for the upstream market: If the monopolist would be required to decrease its market share, wholesale revenues decrease and the incentive to discriminate is raised (Weisman, 1995).

In the case that the upstream monopolist integrates forward and represents a new entrant into the downstream market, Sibley and Weisman (1998) stipulate that for initially low market shares, the integrated firm has no incentive to raise rivals' costs. Analyzing the impact of downstream competition, Mandy and Sappington (2007) confirm the stated results for cost raising strategies in quantity-setting (Cournot) and price-setting (Betrand) competition, as well as cost raising sabotage in quantity-setting competition, but find opposing results for quality reducing behavior in price-setting competition.

Brito et al. (2012) analyze quality degradation in the presence of product differentiation. The authors show that the integrated firm has an incentive to discriminate, if the competitor provides an inferior product compared to its own subsidiary and the upstream margin is sufficiently low. They further show that a disparity in quality and low access prices may also lead to discrimination in the separation case, since the upstream firm benefits from a larger market share of firms that produce superior quality products.

With regard to regulated upstream prices, the integrated firm has an unambiguous incentive to discriminate if the access charge is set equal to marginal costs of providing the input (Sibley and Weisman, 1998; Kondaurova and Weisman, 2003; Reitzes and Woroch, 2009). Obviously, the monopolist will engage in sabotage since there are no opportunity costs in terms of lost wholesale profits. Only in the case of price competition this result may be reversed (Mandy and Sappington, 2007).

Reitzes and Woroch (2009) highlight the fact that pricing parity in the form of cost-based regulation incentivizes the upstream firm to provide excessive quality to its integrated affiliate, allowing it to charge higher access fees to its downstream competitors while degrading their input quality.

**Double marginalization** A well known beneficial effect of integration in terms of consumer and total welfare is the elimination of markups that may exist in a vertically separated industry. Except for the case of a perfectly competitive downstream market, double marginalization leads to the contraction of output and higher retail prices if price discrimination is difficult. In contrast, if the upstream monopolist is able to discriminate, e.g., by two-part tariffs, no double marginalization occurs, but at the costs of full monopoly profits. Under integration, i.e., common ownership, the subsidiary will consider the actual upstream production costs instead of the access price as marginal costs (Brito et al., 2012). Thus, double marginalization is also prevented in the case of linear tariffs (Riordan, 2008).

**Economies of scale and scope** Proponents of vertical integration point out that separation prohibits the exploitation of substantial economies of scale and scope. In fact, empirical analyses in adjacent network industries have obtained mixed results. While other utility industries may have rather different technological characteristics and the magnitude of efficiencies may depend on the historical development of the sector, they share the necessity of high sunk upfront investment costs in the upstream market that have to be geared to the needs of the downstream services. In a conceptual comparison of the vertical structure in infrastructure sectors Pittman (2003) discusses the respective magnitude of vertical economies, but concludes that rapid technological change in the telecommunications sector complicates the formulation of a universal hypothesis about the extent of these efficiencies. Thus, in the light of the following ambivalent empirical results obtained for other infrastructure industries, one should abstain from a per se hypothesis that vertical economies are exceedingly high in general. Kwoka (2002), finds evidence for economies of scope in the US electricity sector. In particular, economies of coordination between generation and distribution are identified as the main drivers of integration. These findings are in accordance with the early work of Kaserman and Mayo (1991) and similar results were replicated for the Spanish electricity market (Jara-Dıaz et al., 2004). However, it is further shown by Kwoka that there are potential instruments besides integration to achieve effective coordination. In particular, holding companies above a certain size can adequately substitute the coordination function of the integrated firm. In contrast to these studies, Nemoto and Goto (2004) find almost no economies of vertical integration for a set of Japanese utilities, while Garcia et al. (2007) show that no significant technological integration economies can be observed in a sample of the US water industry. Lafontaine and Slade (2007) report on the results of four studies that have investigated the effect of mandated separation in the gasoline refining and sales industry. They find an unambiguous negative impact on consumer surplus through higher costs and prices. Based on a conceptual analysis, De Bijl (2005) argues that separated operators face higher financing costs due to a lower scale compared to the integration scenario. Crandall and Sidak (2002) argue that mandated separation will create arbitrary and artificial boundaries that lead to inherently inefficient organizations. Furthermore, they refer to the indivisibility of intangible assets such as customer loyalty and goodwill. Additional costs are induced when separation is imposed on an initially integrated firm. Functional as well as ownership separation require costly structural reorganizations and the redesign of business processes (Cave, 2006b).

**Dynamic incentives** Several scholars have argued that a lack of coordination has a negative impact on the efficiency of investments (De Bijl, 2005; Crandall and Sidak, 2002; Tropina et al., 2010). In a more differentiated analysis, Iossa and Stroffolini (2012) show that integration is particularly beneficial when little demand information is available, infrastructure cost is low, or investment is highly risky. Moreover, Crandall et al. (2010) has stated that separation creates a hold-up problem due to the inability to specify complete contracts. In contrast, Cadman (2010) argues that the hold-up problem is resolved by a sufficiently competitive downstream market.

Farrell and Katz (2000) have shown that integrated firms may have an incentive to engage in an “investment squeeze", forcing downstream competitors to engage in excessive investments. In fact, investment incentives in the downstream market may be strengthened by vertical separation. Since firms expect less discriminatory behavior in this case, perceived uncertainty is reduced and relationship-specific investment may be increased (Cadman, 2010).

With respect to the incentive to duplicate infrastructure, the consensus indicates that separation will diminish the incentives for future entry in the upstream market (De Bijl, 2005; Tropina et al., 2010). To some degree, this can be seen as the consequence of mitigated incentives for anti-competitive behavior by the upstream monopolist.

**Regulatory and legal aspects** The literature has described several advantages of vertical separation from a regulatory perspective. The break-up into two separate organizations increases transparency, therefore making it significantly easier to oversee the behavior of the upstream monopolist (Cadman, 2010; Pittman, 2003). Moreover, the separation of business activities prevents distortion of competition through cross-subsidization. Even in the case of vertical integration, the ability to impose separation alone can be an effective instrument to motivate the monopolist to adapt its behavior to regulatory rules (De Bijl, 2005). On the other hand, the decision to impose separation may be approached with caution. Due to the high costs of separation, the process is considered to be irreversible (Teppayayon and Bohlin, 2010). Especially in the case of high uncertainty about the outcome of separation, regulators should therefore abstain from mandated separation.

**Implications** Static efficiency effects in integrated telecommunications industries have been thoroughly examined by the economic literature. Integrated operators are shown to benefit from economies of scale and scope as well as low information costs between the retail and wholesale division. The inherent incentive to price-discriminate has traditionally been countered with regulating wholesale prices, which in turn raises the issue of non-price discrimination, e.g., by raising rivals' costs through sabotage. At the same time the implementation of regulatory control is faced with imperfect information.

OA, in the narrow sense, may represent an opportunity to take a first step towards deregulation by abstaining from price regulation. Non-discrimination obligations may facilitate regulatory monitoring by equivalence of input conditions or more easily ob-

TABLE 2.1: *Summary - Vertical Integration & Separation.*

| Description | Int. | Sep. | Description & References |
|---|---|---|---|
| **Static efficiency** | | | |
| Double Marginalization | (+) | (–) | The subsidiary of an integrated firm considers the actual marginal costs of upstream production (Riordan, 2008; Brito et al., 2012). |
| Restoring monopoly power | (–) | (0/–) | Through integration the upstream monopolist can overcome its commitment problem. (Rey and Tirole, 2007b). |
| Price discrimination | (0/–) | (0/–) | In the absence of regulation, integrated firms may have incentives to engage in a price squeeze (Vickers, 1995; Farrell and Katz, 2000; Lafontaine and Slade, 2007). Under separation this anticompetitive incentive is eliminated, however, an uncontested upstream monopolist will charge more efficient firms a higher price. (DeGraba, 1990; Inderst and Valletti, 2009). |
| Non-price discrimination | (0/–) | (0) | In the case of price-regulation, the integrated operator is likely to distort downstream competition, but particular exceptions exist (inter alia: Economides (1998); Mandy (2000); Brito et al. (2012)). |
| Economies of scale | (0/+) | (–) | Larger scale decreases financing costs (De Bijl, 2005). |
| Economies of scope | (0/+) | (–) | Empirical evidence of scope advantages in the electricity industry (Kwoka, 2002; Jara-Dıaz et al., 2004). Contrary results in the case of Japanes utilities (Nemoto and Goto, 2004) and the water industry (Garcia et al., 2007). |
| Separation costs | (0) | (–) | Redesign of business processes (Cave, 2006b). Artificial boundaries lead to inefficient organizations (Crandall and Sidak, 2002). |
| **Dynamic efficiency** | | | |
| Coordination of investments | (+) | (0/–) | A lack of coordination may lead to inefficient investment (De Bijl, 2005; Crandall and Sidak, 2002) |
| Hold-up problem | (+) | (0/–) | Separation and incomplete contracts lead to opportunistic ex-post behavior delaying investments (Crandall et al., 2010). Resolved by a sufficiently competitive downstream market (Cadman, 2010). |
| Investment squeeze | (–) | (0) | Integrated firms may force downstream competitors to engage in excessive innovation (Farrell and Katz, 2000). |
| Upstream investment incentives | (+/–) | (–) | Ambivalent effects under integration (Cambini and Jiang, 2009). Reduced incentives for infrastructure-based competition in the case of separation (Tropina et al., 2010; De Bijl, 2005). |
| Downstream investment incentives | (–) | (+) | Trust induced by separation decreases perceived uncertainty (Cadman, 2010). |
| **Regulation** | | | |
| Transparency | (–) | (+) | Separation facilitates regulatory oversight (Cadman, 2010; Pittman, 2003; Economides, 1998) and prevents cross-subsidization (De Bijl, 2005). |
| Coercion | (0) | (+) | The regulator's ability to impose separation can be used as coercive instrument (De Bijl, 2005). |
| Irreversibility | (0) | (–) | The decision to separate can not be reversed ex-post, while effects may be uncertain ex-ante (Teppayayon and Bohlin, 2010). |

Note: The signs (+), (0), and (–) qualitatively indicate the consensus of the surveyed literature on whether the issue has a positive, neutral, or negative impact, respectively, on the efficiency goals or the regulatory and legal requirements. For instance, the first row indicates that static efficiency is increased (decreased) due to double marginalization under integration (separation). (+/–) points to contradictory theories or evidence while (0/+) or (0/–) represent intermediate measures. This notation applies equally to the subsequent tables.

tained benchmarks for margin squeeze tests.[2] Moreover, imposing OA in the case of an integrated access provider can potentially increase the transparency of wholesale offers and prices, therefore lowering transaction costs for wholesale agreements and entry barriers to service-based competition. However, further research is needed in order to decide whether particular OA implementations can contain opportunistic behavior by the integrated operator.

Ensuring OA by imposing separation of upstream from downstream activities represents an effective instrument to counter non-price discrimination by removing the underlying incentives to discriminate against particular downstream firms and by simplifying regulatory oversight. However, the regulator has to be aware that these gains come at the costs of double marginalization, increased transaction costs, substantial separation costs, and diseconomies of scale.

The literature on dynamic efficiency points to ambivalent effects with respect to upstream investment incentives. Further research is expected in this area in order to clarify and quantify particular investment incentives. For instance, the coordination of investments by internalizing incentives of the downstream market is generally stated as a strong argument in favor of integration. However, this proposition may have to be reevaluated in the context of NGANs. Due to a layered architecture founded on the universal IP standard and the perception that fiber technology will not present an "innovation bottleneck" soon, the negative impact on innovation may not be that substantial in the short term.

### 2.2.2 Co-investment

Bourreau et al. (2012a) present a brief summary of the advantages and disadvantages of co-investment. Accordingly, cost-sharing and risk-sharing rules have the potential to increase NGAN coverage and enhance consumer surplus. They point out that the

[2] See Chapter 4 for a theoretical and Chapter 6 for an experimental analysis of margin squeeze tests in the context of infrastructure and wholesale competition.

frequently mentioned benefits of cost sharing are directly associated with sharing the subsequent revenues. Therefore, the business case of the particular investment project does not improve, unless the co-investment approach leads to more product differentiation in the downstream market, subsequently inducing a demand expansion effect.

Nitsche and Wiethaus (2011) characterize risk-sharing as an alternative to regulatory instruments such as cost-based price-regulation (more specifically long-run incremental costs (LRIC)), fully distributed costs regulation, and regulatory holidays. In the case that there is no access regulation or risk-sharing agreement, no access to the downstream market is provided to the entrant ex-post. Risk-sharing is found to induce the strongest degree of competition compared to all other regulatory regimes and to attain a higher level of investment than the LRIC approach.

Rey and Tirole (2007a) discuss different rules that govern the access to cooperative undertakings for future entrants. In particular, they compare the models of non-discriminatory and fully discriminatory cooperatives. While the former allows later members to join an existent cooperative and use the established infrastructure by paying a cost-based access charge, the latter charges an entry fee in addition to the access charge. It is shown that investment is discouraged by an “open access" policy since future entry will marginalize profits to zero. In contrast, investment is encouraged by a “closed access" model, but at the same time, excessive restriction of access leads to a suboptimal outcome from a welfare standpoint. Therefore, Rey and Tirole conclude that the access model involves the essential characteristics of the trade-off between static and dynamic efficiency (see, e.g., Gayle and Weisman, 2007). In order to improve social welfare, the authors suggest to either constrain the market power of closed cooperatives or to give open cooperatives an instrument to protect their investment partially.

Krämer and Vogelsang (2016) investigate collusive behavior in cost-sharing undertakings in an experimental setup. The authors find that co-investment affects retail prices by two contrary effects with a similar magnitude. On the one hand, co-investment increases prices by facilitating tacit collusion in downstream markets. On the other hand, reduced investment costs due to co-investment are passed on to consumers. Moreover, the communication between firms, a necessary prerequisite to co-investment, is found to have a positive impact on investment.

Inderst and Peitz (2012) show that ex-ante access contracts reduce the incentive to duplicate infrastructure, but increase the area that is covered by at least one network compared to investment under ex-post contracts. At the same time, they show that reduced duplication allows the access provider to engage in price discrimination against independent downstream firms under the general assumption that aggregate demand of the market is price-dependent. Consumers are therefore harmed by potentially higher downstream prices, but may benefit from ex-ante contracts making investment profitable in the first place. The authors also mention that ex-ante contracts will naturally mitigate the hold-up problem, since the ex-ante commitment prohibits ex-post haggling by the access seeker.

Bourreau et al. (2013) agree that ex-ante cooperative agreements can potentially increase coverage, but qualify these results subject to particular conditions. The authors show that the results hold only in the presence of a demand-expansion effect, high cost savings from joint investment or a combination of both. While the former may be induced by high service differentiation the latter is especially pronounced in the case of high uncertainty. Under mandated access regulation, investment incentives are reduced since the agreement to an ex-ante contract is now presented with a forgone option in the future. As in the case of unilateral investment, coverage decreases with lower access prices. On the contrary, under a voluntary access regime, coverage is increased at the cost of a less competitive downstream market.

**Implications** In summary, the literature indicates that the cooperative undertakings face a similar trade-off between static and dynamic efficiency with regard to access as in the case of unilateral investment. The introduction of a temporal dimension, how-

TABLE 2.2: *Summary - Co-investment.*

| | Effect | Description & References |
|---|---|---|
| **Static efficiency** | | |
| Cost reduction | (+) | Instrument to lower financing costs, lower up-front costs per operator but joint production may exhibit diseconomies of scale (Bourreau et al., 2013). |
| Collusion | (–) | Experimental evidence of tacit price collusion (Krämer and Vogelsang, 2016). |
| Downstream Competition | (+/–) | Multiple firms in downstream market while avoiding duplication and regulation, ex-ante contracts can be used to dampen competition (Inderst and Peitz, 2012). |
| **Dynamic efficiency** | | |
| Uncertainty | (+) | Spreading overall risk facilitates investment (Bourreau et al., 2013). |
| Investment incentives | (+/0) | Strong incentives for closed cooperatives, weak incentives for open cooperatives (Rey and Tirole, 2007a). Ex-ante contracts increase coverage and decrease duplication (Inderst and Peitz, 2012). Coverage only increases if there exists a demand expansion effect (Bourreau et al., 2013). |

ever, may present opportunities to balance this trade-off. The regulator may prescribe (open) access ex-ante, i.e., before the investment, but not ex-post. The results obtained by Nitsche and Wiethaus (2011) point towards this direction, but need further assessment and robustness tests in more general settings (Inderst and Peitz, 2012). In particular, this raises the question about adequate parameters to balance this trade-off in the context of co-investment. For instance, what would be the necessary number of co-investment participants to secure downstream competition while abstaining from access regulation. This is related to the more general issue currently debated in European mobile telecommunications market: What is the minimum number of market participants that is necessary to establish a competitive market? This latter question is addressed in Chapter 6.

The context of cooperation opens the analysis to a broader behavioral evaluation. The results obtained by Krämer and Vogelsang (2016) point to several effects that are neglected by theoretical models. This includes especially the analysis of tacit and implicit collusion during the investment phase and the setting of downstream prices. Identifying the behavioral cause of particular effects may also present new approaches to support regulatory practice. For example, the significant impact of communication itself suggests that improving coordination of investments besides the formation of joint undertakings may already increase dynamic efficiency. Going further, behavioral approaches may not only be suited to identify these effects, but facilitate the design of instruments to govern the interactions as will be shown in Chapter 5.

### 2.2.3 Public-sector participation

In order to provide a brief introduction into the vast literature on the general role of public-ownership, this sections commences with a reference to an overview of the fundamental theories established within and a summary of several empirical surveys on the observed effects of public ownership. Thereupon, two more specific issues that have been related to OA and the deployment of NGANs are reviewed, namely the activities of municipalities and the formation of PPPs.

Summarizing the fundamental insights of the economic literature on private and state ownership, Shleifer (1998) concludes that private ownership should be the preferred option whenever innovation or cost efficiency represent major criteria. The static perspective and the exclusive concern about prices of state ownership deteriorate dynamic incentives and endanger social welfare in the long-run. Instead, government contracting and regulation are qualified as suitable instruments to ensure public goals that avoid an excessive role of the state sector. Moreover, Shleifer (1998) refers to the results presented by the public choice theory which highlight the adverse incentives for government and administration officials under state ownership.

Megginson and Netter (2001) survey the empirical literature on privatization and the relative performance of privately owned firms compared to state-owned enterprises (SOEs). Based on studies from numerous countries, which employ different methodological approaches, the authors are able to offer a number of general and robust conclusions. The empirical literature largely confirms that "privately owned firms are more efficient and more profitable than otherwise comparable state-owned firms" (Megginson and Netter, 2001, p.380). Furthermore, the consensus is that privatization leads to an improved operating and financial performance of former SOEs. Particularly, output, efficiency, profitability and capital investment spending increases in non-transition economies, while leverage significantly decreases.

Dewenter and Malatesta (2001) contribute to the empirical evidence that state-owned firms are significantly less profitable than privately owned firms. The dataset is based on Fortune magazine's list of the 500 largest firms worldwide in the timespan from 1975 to 1995. 147 of the 1369 firm-years sample are for government-owned firms, which are mainly located in Europe. Interestingly, in a survey of privatization procedures no evidence is found that the actual transfer of ownership leads to an increase in profitability. In fact, profitability is primarily increased prior to privatization, while afterwards no significant increase can be observed. This points to a structural transformation of the organization, conducted in advent of privatization, as the actual source of improved profitability.

Examining the privatization of national telecommunication companies, Bortolotti et al. (2002) provide specific empirical evidence for the telecommunications sector based on a global sample of 31 firms in 25 countries. The data set includes full and partial privatizations through public share offerings from 1981 and 1998. In line with the results of the general empirical literature on privatization, significant improvements of financial and operating performance are found. Efficiency gains are explained by better incentives and productivity, while significant cost reductions are also the dominant reason for increased profitability. Again, these improvements cannot solely be attributed to ownership change in most cases, but are also related to accompanying regulatory changes.

In an empirical study of US municipal utilities, Gillett et al. (2006) investigate the determinants that induce these utilities to expand their operations into telecommunications services. The ability to exploit economies of scope stemming from the provision of internal communications services, and the location in markets with limited existing competition are found to be significant variables that lead a municipal electric to enter the telecommunications market. In contrast, rules that aim to impede municipal entry are found to be effective in reducing municipal activity. The finding that rural areas are less likely to be served by a municipal utility is linked to substantial backhaul costs as a constraining factor. Due to the ambiguous impact of demographic variables, Gillett et al. (2006) conclude that the motivation of municipal utilities differs from private organizations. In particular, municipal supply may be motivated by the economic development of financially less attractive areas. Next to their empirical results, the authors stipulate several arguments in favor of a municipal approach: Utilities are depicted as early adopters that can accelerate the growth of NGANs and may represent a superior governance mechanism compared to regulation of a private network operator, if infrastructure-based competition is in fact infeasible.

Ford (2007) presents empirical support for the hypothesis that public investment in communications networks stimulates entry of private telecommunications firms, as opposed to crowding out private activity. The survey is based on a set of municipalities in the state of Florida, USA, of which a subset provides electricity and in some cases communications services. Private activity is measured by the number of competitive local exchange carrierss (CLECs) that are active in the particular market. While the presence of public supply (electricity only) is associated with a lower number of private communications firms, the provision of communications services by the municipality increases the activity in the communications sector above the levels of cities that abstain from self-supply and municipals that provide electricity.

Using a comprehensive dataset that covers the US market from 1998 to 2002, Hauge et al. (2008) investigate market characteristics that may promote entry by municipal telecommunications providers relative to the motivation that may induce entry by CLECs. Based on their empirical analysis, the authors reject the hypothesis that municipal providers base their entry decision solely on expected profits. Interestingly, this is contrary to what the authors find with respect to CLECs. While CLECs are more likely to be located in urban areas with higher income and higher revenue possibility, municipal providers tend to serve complementary areas with higher cost structures and characteristics that predict lower demand. On the other hand, the results indicate a positive, but insignificant relationship between CLEC market participation and the presence of a municipal provider. Hence, the crowding out hypothesis, that the presence of a municipal provider impedes entry by a CLEC, cannot be rejected. In conclusion, the authors imply that municipalities do not represent a significant competitive threat to CLECs and do not impede private market entry.

Troulos and Maglaris (2011), in a qualitative survey of local broadband strategies in Europe, highlight the ability of municipal initiatives to stimulate demand for NGANs. The deployment of Metropolitan Area Networks connecting public institutions, implementation of e-Government services, price subsidization, and strengthened civil participation are presented as public instruments to boost network rollout. The role of municipal broadband as a complementary provider of basic infrastructure in rural areas and as a stimulator of private investments is emphasized. In line with Gillett et al. (2006), utilities which can exploit economies of scope are shown to be a major driver for the decision to provide municipal communications services. Supplementary, European-wide subsidies are seen as a public instrument to resolve the fragmentation and heterogeneity created by municipal approaches. Moreover, accompanying state aid regulation may introduce neutrality as the central principle for supply of access network. On the other hand, the authors mention the discouraging effect of state-owned network infrastructure on duplication incentives, crowding out private investment at the physical infrastructure level.

In a meta-analysis, Hodge and Greve (2007) review the effectiveness of PPPs, in particular, long-term infrastructure contracts with a focus on Europe. The analysis is preceded by a criticism of the extant literature, which highlights the lack of an actual evaluation of PPPs and calls for more empirical analysis which objectively quantifies costs and gains of such collaborations. Previous studies provide contradictory evidence on the performance of PPPs, raising doubts whether promised benefits of PPPs can actually be delivered in practice. Moreover, the results suggest that sector-specific variables have a substantial impact on the performance results. This gives rise to concerns about the accountability in PPPs, due to limited transparency, complexity of the negotiated deals and restricted public participation. In addition, administrative and political decision makers are incentivized by short-term gains, while long term contracts associated with infrastructure projects limit the future flexibility to rectify mistakes or to adapt to a changing environment. With regard to these issues, the authors highlight the importance of different organizational structures and the allocation of responsibility. The cross-country analysis indicates that PPPs in the UK and the Netherlands are implemented as top-down approaches, whereas undertakings in the North European countries and Germany are organized in a more decentralized way.

Gómez-Barroso and Feijóo (2010) summarize the historical and current debate about the respective roles of the public and the private sector in the telecommunications domain in their conceptual classification of recent contributions to the debate on private-public interplay. The authors state that public activity in the telecommunications industry is supported, although not demanded by the consensus of modern economic schools, due to the presence of market failures. The hypothesis that markets are in any case superior with regard to static efficiency is rejected, and instead, a pragmatic logic (Linder and Rosenau, 2000) is endorsed: PPPs should be considered whenever requirements differ from obviously private or public responsibilities. At the same time, the authors are cautious about the performance of PPPs, referring to the results by Rosenau (2000) that PPPs display weaknesses in the long-run and by Yescombe (2011) that PPPs introduce additional complexity.

Developing a theoretical model of incomplete contracts, Hart (2003) draws the conclusion that PPPs should be preferred over individual outsourcing contracts, whenever it is difficult to specify the quality of the infrastructure, but easy to specify the quality of the services. Since a PPP internalizes the operational expenditures, it engages in higher productive investment, reducing these costs, but also in excessive unproductive investment. In the opposite case, when infrastructure quality is easily specified, public outsourcing yields superior results, since it avoids unproductive investment. In conclusion, Hart emphasizes the role of contracting costs and criticizes the general perception that the private sector represents a cheaper source of financing than the state.

Based on a conceptual analysis, Given (2010) studies the reinvigorated role of the public sector and the impact of PPPs in the Australian and New Zealand telecommunications sectors. He finds that the proposed PPPs in telecommunications are not motivated by conventional reasons such as private financing and expertise, but rather by the willingness to assert the pursuit of the public interest. Thus, the drastic steps of separation and nationalization are consequences of the concession that regulation as well as functional separation have proven to be insufficient instruments in ensuring public goals.

**Implications** Participation of the public sector in its various forms can boost coverage and speed of network deployment. However, well-known concerns about cost efficiency, complexity and imperfect information should restrict the scope of public activity. Local initiatives and bottom-up approaches are likely to reduce these mentioned concerns. Moreover, municipal activity is capable of stimulating demand and extending the scope of viable investment cases due to the consideration of societal spill-over effects.

Besides the role as a financing facilitator, the public entity is likely to achieve its highest potential at the civil infrastructure level. Since civil infrastructure costs represent the largest share of total costs (Hoernig et al., 2012), exploiting economies of scope by providing infrastructure such as ducts can reduce deployment costs significantly.

Mandated OA, as stipulated in the European State Aid Guidelines, can help to keep distortion of competition through the crowding-out effect at a minimum. In the context of state-owned access networks, the Australian case will give an indication whether OA can represent an effective alternative to regulation by ensuring the public interest while promoting efficient service-based competition on a neutral basis. However, while direct public control may facilitate the implementation of non-discriminatory access, the literature raises concerns about the adverse incentives of public decision makers and

TABLE 2.3: *Summary - Public-sector participation.*

| | Effect | Description & References |
|---|---|---|
| **Static efficiency** | | |
| Economies of scope | (+) | Utilities that provide internal communications infrastructure are more likely to expand their services (Gillett et al., 2006). |
| Economies of scale | (–) | Municipal approaches are unlikely to serve rural areas due to backhaul costs (Gillett et al., 2006). |
| Cost efficiency | (–) | Private ownership is superior in containing costs (Shleifer, 1998). State-owned firms are found to be significantly less profitable (Megginson and Netter, 2001; Bortolotti et al., 2002). |
| **Dynamic efficiency** | | |
| Stimulation of demand | (+) | Municipal initiatives can stimulate demand (Gómez-Barroso and Feijóo, 2010). |
| Crowding-out effect | (+/–) | Municipal utilities substitutes private market entry (Gillett et al., 2006). Number of CLECs increases if a municipal provides communications services (Ford, 2007). Municipal providers serve complementary areas relative to CLECs (Hauge et al., 2008). |
| Quickness of deployment | (+/0) | Public utilities may serve as early adopters (Troulos and Maglaris, 2011). |
| Viability of investment | (+) | Public investors take into account spill-over effects to adjacent industries (Troulos and Maglaris, 2011). |
| Hold-up problem | (+) | Anticipation of the long-term socio-economic benefits (Troulos and Maglaris, 2011). |
| Innovation | (–) | State ownership neglects dynamic incentives (Shleifer, 1998). |
| **Regulation** | | |
| Neutrality | (+) | State aid rules as a regulatory instrument to mandate non-discrimination (Troulos et al., 2010; Troulos and Maglaris, 2011). |
| Accountability | (–) | Limited transparency and public participation (Hodge and Greve, 2007). |
| Public interest | (+/–) | State ownership as an instrument to ensure public goals representing an alternative to regulation (Given, 2010). Adverse incentives of government and administrative officials (Shleifer, 1998). |
| Complexity | (–) | PPPs "add a substantial layer of extra complexity" (Yescombe, 2011, p.26). |

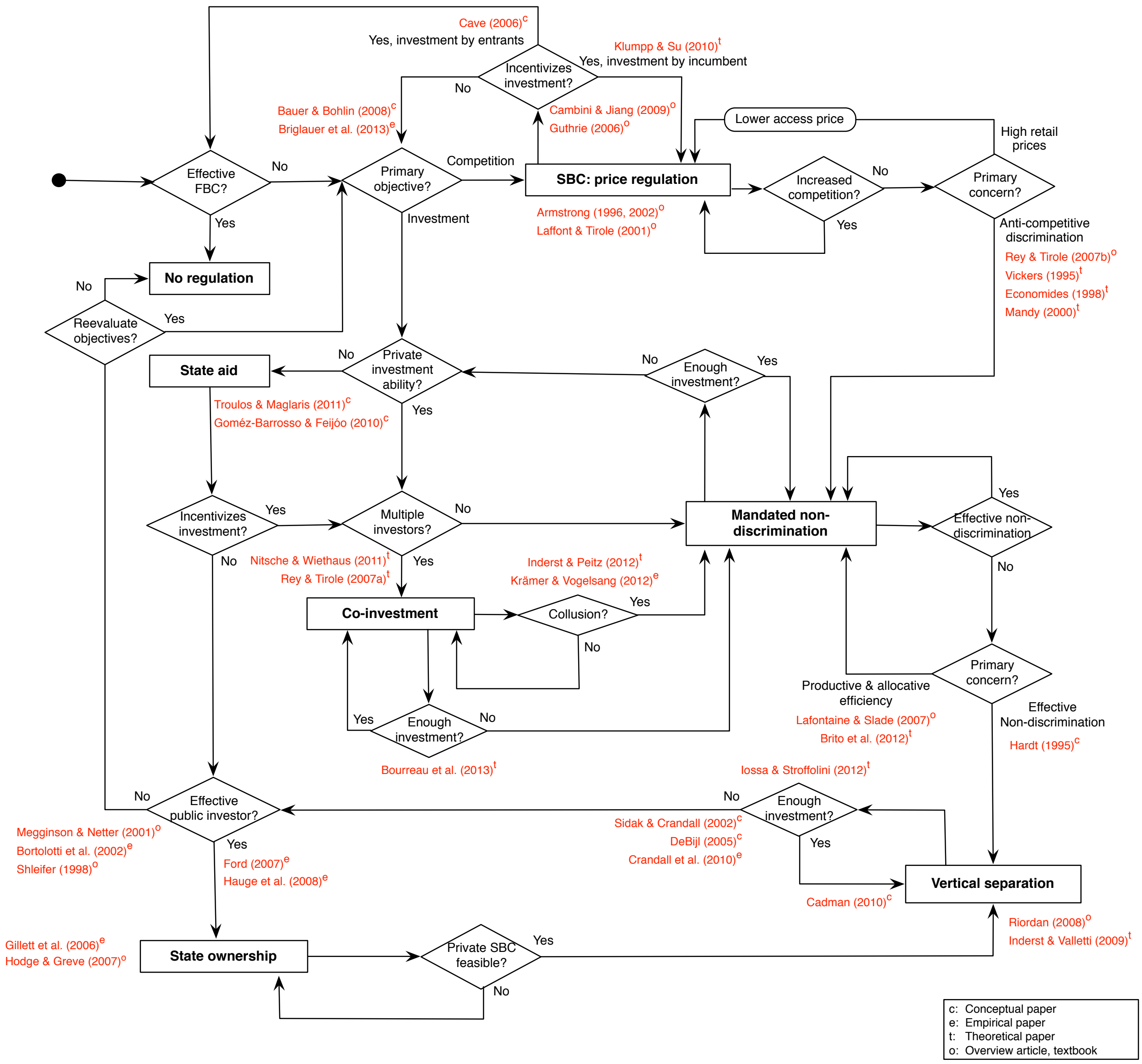
a lack of transparency and accountability in collaborations between state and private organizations.

## 2.3 Policy guideline

Up to now the discussion was concerned with the specific effects of a single OA application. Based on these results, this section addresses how the presented applications relate to each other. The preceding survey of the economic literature has shown that decision makers face multiple trade-offs when deciding for a particular regulatory regime. Therefore, in the context of NGANs, regulators are required to implicitly or explicitly weigh conflicting goals. Figure 2.3 illustrates the decision process proposed to assist regulators in choosing the most appropriate policy instrument, given their primary objective, observed market conditions, and their experience from previously implemented approaches. Rectangles represent the different regulatory scenarios and diamonds represent the key questions that policy makers must evaluate in order to determine the next steps and measures in the regulatory decision process. In this vein, the proposed policy guideline allows for an assessment of the transition between regulatory regimes when objects are not satisfactorily fulfilled, new problems or technological advancements arise, or the relative order of goals is reevaluated.

In order to make transparent where the identified trade-offs are discussed in the literature, references to representative articles are indicated at the respective decision branches. Moreover, it is highlighted whether these articles are overviews or whether they are based on conceptual, theoretical, or empirical analysis. Since the guideline is derived mainly from the findings within the economic literature, its scope is necessarily incomplete and policy advice has to take into account complementary legal and technical considerations. Nevertheless, a visual representation and a predefined structure of the decision process, as laid out in the following, may also facilitate the interdisciplinary discourse between stakeholders.

FIGURE 2.3: *Recommended policy guideline for OA regulation of NGANs.*



The starting point of the proposed policy guideline is the regulatory status quo, which may either be constituted by an existing regulatory framework that is potentially to be replaced or complemented, or by an entirely unregulated industry where new rules are implemented based on a greenfield approach. Given a status quo, an evaluation of whether the existing legal and regulatory framework contributes to desireable sector performance is required in the first place. Policy makers will only be willing to make changes if there is potential room for improvement. The ensuing question of what can and what needs to be done is the underlying question that is addressed by the guideline. In any case, it needs to be verified whether (given the status quo) regulatory intervention is (still) justified at all. This is generally deemed not to be the case if infrastructure or facility-based competition (FBC) is deemed feasible in the relevant time horizon. This would also imply that the essential facility doctrine does not hold (Renda, 2010), or in the case of Europe, that the three-criteria-test will fail. In these cases, deregulation has been suggested to be the optimal choice rather than continued regulation (Cave, 2006a; Vogelsang, 2013).[3]

Given the need for regulation, policy makers must now select their primary objective. This may either be to promote competition (on existing network infrastructure) or to promote investment into new network infrastructure. Although some scholars argue that dynamic and static efficiency goals can be reconciled (Klumpp and Su, 2010), a growing strand of the literature has pointed towards a definite trade-off between these objectives (Bauer and Bohlin, 2008; Briglauer et al., 2013; Guthrie, 2006). The indication of slowly expanding NGANs in Europe seems to support the existence of an efficiency trade-off. Thus, policy makers must inevitably rank either competition or investment as being more important, while of course, trying to achieve the other as good as possible under this constraint. In this vein, this branch offers also a historical perspective. On the one hand, the political and academic debate of the last two decades was centered around the question of how to introduce and sustain a competitive downstream market on the basis of existing networks (Armstrong et al., 1996; Laffont and Tirole, 2001; Arm-

[3]Whether infrastructure competition in combination with wholesale competition in fact induces effective retail competition and thus also benefits consumers under no regulation is investigated in further detail in Chapter 5.

strong, 2002). On the other hand, more recently the need to promote investments in new NGAN infrastructure is considered to be the main regulatory challenge and, e.g., in the context of vectoring (see, e.g., Bundesnetzagentur, 2013a), several regulatory authorities have chosen investment over competition as their primary objective.

If competition is the primary objective, the introduction of service-based competition (SBC) based on *price regulation* is proposed as the first regulatory scenario that should be considered. The policy guideline implies that, in each regulatory scenario, policy makers must continuously evaluate whether the observed or expected market conditions still warrant to continue the current regulatory approach. In the case of price regulation, such evaluation loops are proposed with respect to investment incentives and competition. According to the Ladder of Investment principle (Cave and Vogelsang, 2003; Cave, 2006a), appropriate price regulation may incentivize entrants to invest into new infrastructures themselves. If this occurs, FBC may become feasible after all and regulation can be lifted. In reverse, even under price regulation, the incumbent may have a sufficiently large incentive to invest (Klumpp and Su, 2010), which would then overcome the efficiency trade-off. In this case, there is, of course, no reason to deviate from price regulation. Similarly, if sufficient competition is achieved, there is no reason to change the functioning regulatory framework. If this is not the case, and the regulatory objective is primarily to reduce retail prices, then price regulation should be reevaluated after the access price was lowered. Otherwise, if competition is weak because of anti-competitive (non-price) discrimination, then *mandated non-discrimination* should be considered as an alternative regulatory scenario.

If, however, investment is considered the primary objective, the regulator is next faced with the question whether the private sector is in principle able to provide the necessary investments on its own or whether public-sector involvement is required. Private investment incentives may be fostered by allowing for cooperative approaches if multiple market participants are able and willing to make partial investments. In the case of high uncertainty, *co-investment* may strengthen investment incentives due to enhanced financing conditions and improved utilization of facilities by infrastructure sharing (Bourreau et al., 2013). With regard to competition, co-investment may be, on the one hand, an instrument to allow for multiple competitors in the retail market even in the absence of actual FBC or access regulation. On the other hand, regulators should exercise particular caution with regard to collusive behavior in the case of co-investment as cooperative undertakings provide additional instruments to coordinate behavior among market participants (Krämer and Vogelsang, 2016). In the case of experienced or highly probable collusion among a closed group of partners, *mandated non-discrimination* that allows for OA to the cooperative undertaking may be applied as an additional criterion. However, regulators need to be aware that these conditions, again, have a direct effect on the incentives to form such an undertaking in the first place (Rey and Tirole, 2007a). If co-investment is not a suitable option due to a lack of multiple investors or due to insufficient investments, *mandated non-discrimination* as a stand-alone institution may represent a regulatory alternative to conventional price regulation.

*Mandated non-discrimination* comprises regulatory rules that are especially concerned with providing equal conditions for access seekers relative to subsidiaries of vertically integrated operators. However, instead of prescribing a uniform (cost-based) access price, as in the case of price regulation, these rules give operators increased freedom when setting their wholesale prices. The European Commission's ex-ante margin-squeeze rule (European Commission, 2013a) can be seen as one possible implementation of this principle. Although this approach is sometimes proposed as a suitable approach to balance the efficiency trade-off, there is little evidence on the impact of such rules with regard to the competitiveness of a market and investment incentives. Hence, further theoretical as well as empirical analysis of the actual implementations is required. Due to the increased pricing freedom of access providers in this scenario, regulators need to be particularly cautious about operators' incentives and abilities to discriminate against downstream competitors.

If regulators are primarily concerned with issues of anticompetitive discrimination and less intrusive regulatory rules prove to be ineffective, *vertical separation* may represent a last resort to eliminate the underlying incentives of anti-competitive discrimination. In any case, the decision to force a vertical break-up needs to weigh the expected competitive benefits against the potential losses in productive efficiency (Lafontaine and Slade, 2007) and allocative efficiency (Brito et al., 2012) as well as the affected investment incentives (inter alia, Cadman, 2010; Crandall et al., 2010; De Bijl, 2005). If vertical separation is still considered the best regulatory option, the question whether the upstream infrastructure should be provided and operated by a private or public entity, should be guided by an assessment of the investment incentives of private organizations and by the productive efficiency of public investors regarding the specific input good.

In general, public-sector participation should be considered as a substitute to private activity only when there is no or insufficient private investment. In the case where state ownership allows for the exploitation of efficiencies at specific access levels, public activity at these stages may benefit private activity at higher layers (Ford, 2007), thus representing an exception to the aforementioned general rule. Among the options for public intervention, *state aid* represents the less intrusive and thus the primary option, when investment is the regulator's primary objective and private investments are not expected. In this case, state aid allows for increased spending and greater public control, while maintaining market-driven coordination of activities and complementary resources. If state aid is insufficient to provide necessary investment incentives, *state ownership* provides a more drastic alternative to increase financing capabilities and gives public representatives full control of deployment and operations. However, well-known concerns about low efficiency and financial performance of public investors in general (Megginson and Netter, 2001), and the success of privatization in accordance with liberalization in telecommunications in particular (Bortolotti et al., 2002), should make decision makers skeptical whether the need for higher investments justifies a far-reaching conclusion as full public control. When opting for state ownership, efficiency issues may be mitigated by limiting public activity to the infrastructure level, enabling service-based competition by private businesses on top.

In contrast to state ownership, *no regulation* represents the other extreme on the spectrum of public intervention. Particularly in the case where investment is considered the primary public objective (and competition is deemed considerably less important), it may be the only alternative solution to public investment, if the latter is considered ineffective. By guaranteeing expected rents above the competitive level, investment incentives may be increased compared to competitive scenarios, obviously at the cost of a loss in static efficiency. According to these implications, the guideline explicitly denotes whether the regulator is willing to reconsider its goals or whether it is willing to take such radical measures to stimulate investment.

Of course, at each node, the decision process is not binary in reality, as suggested by Figure 2.3. For example, private investment ability and incentives are likely to differ across geographical areas depending on household density. Thus, state aid may be made available for rural areas, but not for urban areas. If there still remain uncovered areas, public ownership on a municipal level represents a further alternative (Hauge et al., 2008). Nevertheless, it is often useful to think in dichotomous categories, as depicted in the guideline, in order to realize the inherent trade-offs. Hence, each regulatory scenario is reached on the basis of some prerequisites and shall be sustained only if this is warranted by the continuous reevaluation of known issues and expected outcomes. Otherwise more heavy-handed regulatory scenarios may be considered. Thereby vertical separation and state ownership are seen as the last resort of regulation. In reverse, if market conditions change, regulators may evaluate the currently implemented regulatory scenario anew, possibly beginning from the starting point of the proposed policy guideline. Of course, this does not imply that intermediate regulatory scenarios must actually be implemented. The proposed decision process shall rather be understood as guiding policy makers to ask the right questions in the right order. Overall, the proposed approach thereby implements a “carrots and sticks" paradigm, equipping the regulator with more punitive measures if market participants do not comply with the current set of rules, and offering the ability to lift obligations on the other hand if former obstacles are removed.

The policy guideline also illustrates the numerous reasons that can motivate a mandatory non-discrimination regime, like it is currently pursued by the European Commission (European Commission, 2013a). However, to date there exists only very limited experience on the expected consequences of this regime. In fact, there is no consensus on what regulatory measures are required to ensure non-discrimination in practice. While a margin squeeze test could serve as an instrument to counter price discrimination, non-price discrimination is more difficult to monitor (Hardt, 1995). Vertical separation has been discussed as an effective instrument to counter discriminatory incentives, but at the same time raises severe adverse effects on dynamic incentives as well as productive and allocative efficiency.

With regard to the role of the public sector at the supply side, the policy guideline implies that governments should adhere to the principle of subsidiarity. Only when investment is identified as an urgent and absolute primary need that cannot be provided by the private sector, public ownership on a large scale should be considered as a viable option. In such a case, vertical separation should restrict public activity to the infrastructure level, allowing for private activity on higher stages of the value chain. The case of Australia has demonstrated that such a regulatory scenario is a real option. Dissatisfaction with the performance and anti-competitive behavior of integrated network operators have led the Australian government to take over full control of the access network infrastructure and to provide connectivity at the last mile as a public service (Given, 2010). Representing less invasive instruments, state aid, PPP, and municipal activity can serve as transitory and complementary instruments that should be implemented if they are likely to incentivize further private activity. On the other hand, the public sector has the general ability to stimulate network deployment by demand-side measures (Belloc et al., 2012).

## 2.4 Discussion

The investment challenge in the advent of NGANs has introduced a variety of new business and organizational models as well as regulatory governance mechanisms. Within the last ten years the role of the public sector in telecommunications has again taken a turn, increasing its activity through municipal initiatives, PPPs and the deployment of state-owned network infrastructure. In the context of these developments, OA was suggested by regulators, scholars and industry stakeholders alike as a means to balance the inherent trade-off between static and dynamic efficiency. However, mutually contradictory interpretations, implementations in different contexts, and a lack of an explicit definition have prevented a common understanding of the precise meaning of OA, which in turn may have precluded the rise of such regulation.

By proposing an integrative definition and a structural framework to classify OA application scenarios, this review contributes to a common understanding and a differentiated view on the particular OA concepts. In particular, the survey of the extant economic literature highlighted that public-sector participation can potentially stimulate network investment and foster private activity. In contrast, concerns about cost efficiency and accountability should limit state activity to lower access levels where economies of scope are most significant. In this context, OA regulation can be implemented to minimize competitive distortion on higher access levels. Co-investment may represent an additional instrument to strengthen investment incentives in cases of high uncertainty. In this context, OA governing ex-ante access to cooperative approaches may equip regulators with a new instrument to balance static and dynamic efficiency. In the case of vertical integration, OA may provide an alternative to price regulation. In this vein, economies of scope and scale may be exploited while anti-competitive behavior can be contained. At the same time, incentives of non-price discrimination and the effectiveness of a margin squeeze regulation have to be assessed by the regulator through empirical analysis. Vertical separation is likely to reduce non-price discrimination, but comes at the costs of structural reorganization and is expected to reduce incentives for facility-based competition.

At last, possible extensions and limitations of the herein proposed conceptual framework and policy guideline are pointed out. First, it must be noted that the presented literature survey and decision framework are necessarily incomplete as they are focused on regulatory instruments that fall under the proposed definition of OA. For example, the current outline does not include geographically segmented regulation or regulatory holidays, which, similar to state aid, co-investment and mandated non-discrimination, represent additional deviations from traditional access regulation that could foster investment in NGANs. However, it can be argued that these policy instruments are rather complementary to the considered regulatory scenarios. Hence, it should be possible to include them in the proposed policy guideline. Yet, research on the interaction between these instruments and the different OA scenarios is scant, particular with respect to geographic segmented regulation. Thus, future research is required before such an extension can be proposed comprehensively. Moreover, NRAs need to complement the presented analysis, which is based on economic arguments, by considering legal and technical issues that have not been discussed in this chapter.

Second, the proposed policy guideline highlights that there generally exists a trade-off between static and dynamic efficiency. However, it is worth mentioning that this trade-off is not necessarily linear. For instance, empirical findings by Aghion et al. (2005) suggest that the relationship between competition and innovation is characterized by an inverted-U shape, i.e., innovation is the greatest for intermediate levels of competition. On the other hand, the general validity of this relationship is questioned by other studies (see, e.g., Sacco and Schmutzler, 2011).

Third, for the sake of clarity, the previous discussion was based on only two of the three identified dimensions of the OA framework. Evidently, each OA scenario can be subdivided again with respect to the level at which access is provided. Generally, access to lower network layers (representing high rungs of the ladder of investment concept), allow for a higher degree of quality differentiation and innovation by entrants, since this enables them to exert more physical control over their resources. Consequently, the access level also has an immediate impact on investment incentives and the scope of non-price discrimination, for example, which may then influence the evaluation at different nodes of the proposed policy guideline. Currently a set of different technologies and architectures are implemented in order to realize NGANs, establishing a heterogeneous landscape at the physical access level. However, at the same time, NGANs implement IP as the uniform interface at the network layer. This enables widespread availability of bitstream access, which provides logical unbundling of data flows on the identical physical connection. Since standardization of access products across technologies may play a large role in platform competition comprising telephony networks, cable networks and mobile solutions, bitstream access could significantly decrease transaction and integration costs. Furthermore, given the tremendous increase in transmission capacity that can be achieved by NGANs, there is reason to believe that bitstream access provides a sufficient access level for vital competition and quality differentiation. Finally, bitstream access as an infrastructure technology-transparent interface may provide a means to specify a harmonized access product across EU member states, which could represent as a key regulatory instrument to realize an integrated European digital single market as suggested in the initial proposal for the Connected Continent legislative package by the European Commission (2013e).

Fourth, the discussion of the proposed OA framework was exemplified on the basis that the monopolistic bottleneck, to which access shall be warranted, is constituted by the network layer. However, considering the entire ICT value chain, additional bottlenecks may exist further downstream. These may then not be under the control of the incumbents, but rather be controlled by so-called over-the-top content providers. In particular, such bottlenecks can be constituted by platforms (e.g., app stores or social networks). In this context, it is noted that the proposed framework may also be applied to characterize (open) access relationships at the application layer, using the same basic dimensions (ownership, vertical structure, access level), but, of course, with different characteristics of each dimension. For instance, in the case of platforms, the access level may be differentiated according to features of the application programming interface (API) that is provided. Nevertheless, mandating access at higher levels of the telecommunications value chain is obviously only warranted in case there is a significant market failure, e.g., due to inefficient pricing and a lack of replicability. On the one hand, two-sided platforms have an inherent incentive to price efficiently (cf. Rochet and Tirole, 2006) which implies that market failures are unlikely to occur. On the other hand, network effects may constitute substantial entry barriers that limit replicability. Thus, the case for mandating access at the application layer must be closely scrutinized.

# Chapter 3

# Theoretical Foundations and Experimental Methodology

THIS chapter elaborates on the methodological foundations for theoretical and experimental investigations carried out in this thesis. First, Section 3.1 touches on basic questions in the field of philosophy of science from an applied perspective and discusses the virtue of theory and theoretical analysis in the field of IS as well as the interplay between theoretical and empirical research in the context of market design. Specifically, it is argued that a microeconomically founded research approach is well suited to guide scientific inquiries in the field of IS in general, and to answer the presented research questions in this thesis in particular. Therefore, an idealized research process cycle is proposed, which demonstrates how IS and IO research may complement each other in the task to guide the theory-informed design of markets and regulatory institutions. Building on the presented research ideal, Section 3.2 substantiates how theoretical models and economic laboratory experiments can be employed to serve as a testbed for the validity and robustness of theoretical predictions as well as new design proposals. Finally, Section 3.3 explores a particular methodological question in the context of laboratory experiments and examines the various time frameworks that have been employed in experimental settings. Thus, the section compares decision making under continuous and discrete time, and in particular considers oligopoly competition under continuous time, which allows for real-time, asynchronous strategic interaction. In order to assess the methodological implications of oligopoly competition in continuous rather than discrete time, a laboratory experiment studies the effects on tacit collusion under both time frameworks, taking into account the mode of competition and the number of competitors.

## 3.1 Microeconomically founded research in Information Systems

Arguably, the main purpose of IS research, like most other research disciplines, should be the development of robust theories, which can then inform society about the likely answers to research questions. Notable, although not unique, about IS research is that the research questions that are pursued are not only concerned with the *understanding*, *explanation* and possibly *prediction* of real world phenomena, but also with how the institutions (North, 1991; Roth, 2002) that govern these phenomena in order to achieve a certain goal (cf. Gregor, 2006) can be shaped. In this regard, IS research takes a theory-guided *engineering* perspective.

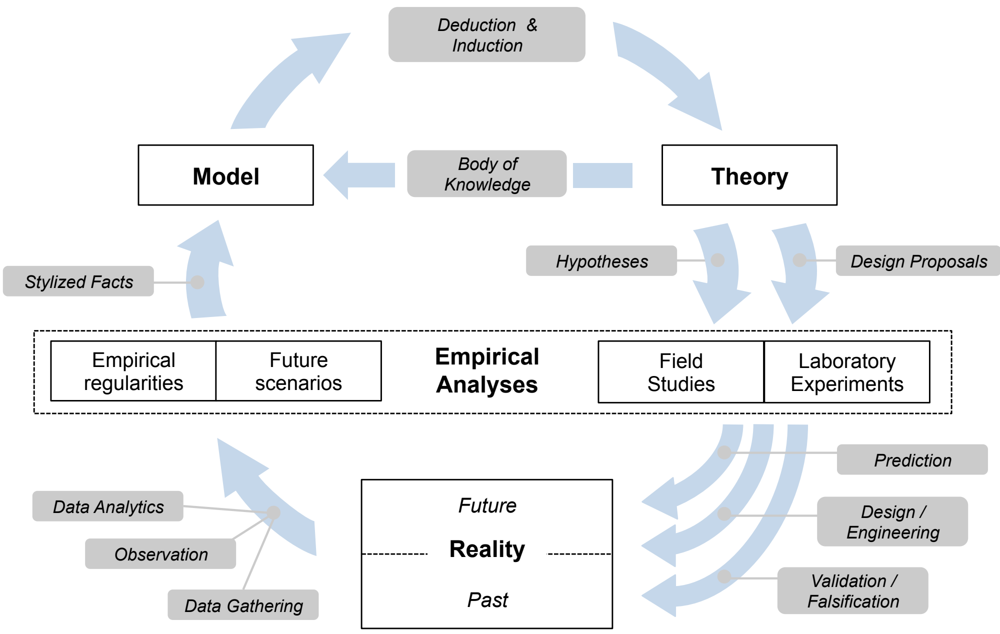
In this vein, *design* in the IS domain does not only refer to the creation and evaluation of software artifacts, but encompasses a much broader scope. In particular the economic context including markets and competitive interactions that evolve around ICT systems represent a major determinant for the success of information systems (Gimpel et al., 2008). Taking into account this dimension is vital to reap and maximize the benefits from advancements of communications and information technology. More specifically, with regard to the domain of ICT markets, it is of particular interest *why* an observed (e.g., technology induced) market behavior occurs, *which* market outcomes are likely under a given scenario, but also *how* markets and the respective regulatory framework should be designed in order to achieve a desirable outcome.

This section is based on joint work with Jan Krämer (Krämer and Schnurr, 2016).

In this section, an idealized microeconomically founded IS research process cycle, depicted in Figure 3.1, is presented, which suggests how analytical and empirical research approaches may complement each other as building blocks to advance robust theory development. In particular, it is emphasized that fruitful IS theories can be built upon formal, analytic models. Such models are in turn founded upon both, stylized facts that are derived from empirical regularities observed in reality, as well as the existing body of knowledge stemming from robust theories. Here, reality refers to the object and processes of investigation that research intents to describe or understand. Scientific inquiries are either concerned with realizations of the *past* or with potential *future* states. Researchers perceive reality through empirical observation and data gathering, which is naturally constrained and imperfect. Models, which in themselves are the foundation of theory, can then be used to explain, predict and design instances of the real world. Finally, models, and thus also theory, are evaluated and refined with respect to their ability to inform society about past or future real world phenomena. This can be achieved in field or laboratory studies either by validating or falsifying theory-guided hypotheses, comparing a theory's predictions with actual future outcomes or by evaluating the success of theory-informed design proposals and engineering approaches in actual applications.

The herein described research process ideal is more specific than (but not contradictory to) more general IS research approaches (cf. Frank, 2006), such as design science (cf., e.g., Hevner et al., 2004). Nevertheless, it is argued that theories developed under this framework are suitable to pursue all four fundamental goals of IS research, namely analysis, explanation, prediction, and prescription/design (cf. Gregor, 2006). It is not the intention, however, to evaluate or judge different IS research approaches, but rather to motivate why the proposed microeconomically founded research framework can serve as one of several appropriate means to rigorously develop relevant IS theories, in general, and to provide a theoretical foundation for the methodological approaches employed in the subsequent studies, in particular.

FIGURE 3.1: *Idealized microeconomically founded IS research process cycle.*




Subsequently, the building blocks of microeconomically founded theory development are described in further detail: Subsection 3.1.1 elaborates on the conception of theory, Subsection 3.1.2 reflects on the role of (analytic) models and Section 3.1.3 examines the role of empirical research methods. Finally, Subsection 3.1.4 discusses concerns of whether there is in fact too strong of an emphasis on theory in scientific practice (cf. Hambrick, 2007).

### 3.1.1 Theory as a set of models

In general, theory has been characterized as the "basic aim of science"(Kerlinger, 1986, p.8) and is often referred to as "the answer to queries of why" (Kaplan and Merton cited by Sutton and Staw, 1995, p.378). According to Weick (2005) a theory may be measured in its success to "explain, predict, and delight" (p.396).

The precise understanding of *theory* here is based on the premise that the main task of theory is the integration of findings of individual studies into a modular, but coherent *body of knowledge* that connects research agendas based on a shared terminology and which provides a *microfoundation*. Revision and extension of theory is achieved in iterative steps through new or modified models that may either re-investigate central assumptions, thus deepening theory's microfoundation, or create meta-models by further abstraction based on the existing body of knowledge. By this means, a *microfounded* theory serves as an anchor (Dasgupta, 2002) and provides building blocks for new research projects and further theory-building.

According to this view, robust theories are the result of deduction and induction from a host of formal models. Therefore, theory can be viewed as a classified set or series of models (Morgan and Knuuttila, 2012). In philosophy of science this integral role of models as a part of the structure of theory has been supported by the Semantic View and has been further emphasized by the Pragmatic View (Winther, 2015). Consequently, a clear distinction between theory and its models is difficult in general, and even more so if the analysis of theoretical models is deemed as the central part of scientific activity.

At the extreme, a single model may already be the foundation of a theory, although probably not a very robust one. In this regard, the understanding of a robust theory in the social sciences may differ from the understanding of a robust theory in the natural sciences, because theory in the social sciences can be very context dependent, as subjectivity of decision makers, i.e., their beliefs, information, and view of the world substantially shape their choices and actions (Hausman, 2013). For example, Dasgupta (2002) noted that "the physicist, Steven Weinberg, once remarked that when you have 'seen' one electron, you have seen them all. [...] When you have observed one transaction, you have not observed them all. More tellingly, when you have met one human being, you have by no means met them all" (p.63). This is why a robust theory in the social sciences should regularly be built upon a set of models, each of which takes a different perspective on a particular issue and explores a slightly different set of assumptions, such that the boundaries of the theory become transparent.

### 3.1.2 Models as mediators between theory and reality

This understanding of theory shifts the attention to the development of suitable models. Models as *idealizations* (Morgan and Knuuttila, 2012) serve as representations of reality that are obtained by simplification, abstraction (see, e.g., the work of Cartwright, 2005; Hausman, 1990) and/or isolation (Mäki, 1992, 2012). But they may also be created as pure *constructions*, i.e., exaggerated caricatures (Gibbard and Varian, 1978), fictional constructs (Sugden, 2000) or heuristic devices that "mimic [...] some stylized features of the real system" (Morgan and Knuuttila, 2012, p.64). Gilboa et al. (2014) suggested that economic models serve as analogies that allow for case-based reasoning and contribute to the body of knowledge through inductive inference rather than through deductive, rule-based reasoning. The use of formal, analytic models in this context can be advocated, because such models allow to make the assumptions transparent that may lead to a proposition and possibly a normative statement upon which a robust theory, and ultimately a robust explanation or prediction can be built. Note that mathematical formalization is a sufficient, but not a necessary prerequisite to develop a formal model, because it allows to precisely formulate its subject domain, making it an "exact science" (Griesemer, 2013, p.299). Moreover, Dasgupta (2002) argued that in building a theory "prior intuition is often of little help. That is why mathematical modeling has proved to be indispensible" (p.70f). The analytic approach provides researchers with a toolbox to deal with especially hard and complex problems. By the means of logical verification, propositions can be shown to be *internally* true with regard to the underlying assumption.

In general, the goal of a model is to "capture only those core causal factors, capacities or the essentials of a causal mechanism that bring about a certain target phenomenon" (Morgan and Knuuttila, 2012, p.53). Such an abstraction is the prerequisite for conducting a deductive analysis within a particular scenario of interest. What is considered to be particularly important in order to develop relevant models is that a model's microfoundation should contain elements of both theory and reality. On the one hand, a model's assumptions should reflect *stylized empirical facts* that are well grounded in observed empirical regularities or relevant future scenarios. Such empirical facts can be derived directly from gathered data (most likely with measurement error), may already be the result of extended data analysis, e.g., in the form of detected patterns or correlations, or may be identified by means of a literature review (Houy et al., 2015). However, stylized empirical facts need not (yet) be supported by any theory. Thus, it is also possible to incorporate insights of theory-free empirical analysis (particularly (big) data analytics or machine learning) into formal models, which may then lead to a theory that can explain the empirical regularities.[1] On the other hand, a model's assumptions may also be derived from the existing body of knowledge, i.e., from theory. This exemplifies the dual view on the relationship between models and theory: Although models are used to advance theory, theory is also used to produce and inform models.

A main line of attack against analytic models is to argue that they are not *realistic* and thus, model-driven theory is useless, because there is nothing to learn about reality. This criticism is amplified in the field of social sciences, where models are context dependent, as argued above. This naive understanding, however, falls short. First, as mentioned above, "good" models should be grounded in stylized empirical facts. Second, there is an inherent trade-off between accuracy and generality, achieved trough simplicity (Gilboa et al., 2014). Scholars experienced in the domain of modelling generally agree on the fact, that too much complexity in fact impedes the explanatory power and the interpretability of models. For example, Schwab et al. (2011) stated that in order "to formulate useful generalizations, researchers need to focus on the most fundamental, pervasive, and inertial causal relations. To guide human action, researchers need to develop parsimonious, and simple models that humans understand" (p.1115). In the words of Lucas (1980) "a 'good' model [...] will not be exactly more 'real' than a poor one, but will provide better immitations" (p.697). In this context, the statistician George

[1] In this context, it is worth mentioning that although data analytics may be able to predict *what* will happen in a specific context, similar to a theory, it is still theory-free, because it is generally not able to explain *why* it happens. Without theory, however, it must remain unknown whether these predictions can be generalized and and to what extent they are robust to other application scenarios. Therefore, data analytics differs from the traditional paradigm of empirical analysis, which centers around the falsification or validation of hypotheses, which again requires a theory (although not necessarily in the same sense as proposed here - see, e.g., Diesing (2008) for a more elaborate discussion of the relationship between empirical and formal theory) from which these hypotheses are derived in the first place.

Box coined the famous phrase that "all models are wrong, but some are useful" (Box, 1979, p.2), clarifying that a model must inherently be *unrealistic* in a dogmatic sense (see Mäki, 2012, for a discussion), but that models in fact enable one to understand *real* phenomena by abstracting from the complexity of reality. To exemplify this, Robinson (1962) argued that "a model which took account of all the variegation of reality would be of no more use than a map at the scale of one to one" (p.33). Of course, an interesting model must also exceed a pure tautology, i.e., the results that can be deduced from its assumptions are usually not a priori clear, but may represent surprising results (Koopmans, 1957; Morgan and Knuuttila, 2012). This requirement can be paraphrased by a quote that is supposedly due to Einstein: "Everything should be made as simple as possible, but not simpler" (cf. O'Toole, 2011).

Furthermore, it is emphasized that over and beyond the explanatory function of formal models, the modelling process itself may prove to exhibit value for understanding a particular scenario. Moreover, a model is an instrument to express an individuals' perception of a problem and may therefore serve as a communication device. Gibbard and Varian (1978) stated that "perhaps, it is initially unclear what is to be explained, and a model provides a means of formulation" (p.669).

### 3.1.3 Empirical analyses as the means to evaluate theory

According to this theory-centric research view, empirical analysis serves two core functions: i) As described above, empirical analysis is a means to derive stylized facts in order to motivate model assumptions, or likewise, to evaluate the plausibility of proposed assumptions. ii) As will be described next, empirical analysis is also a means to evaluate the quality of a theory as a whole. In the context of IS research, three main ways in which evaluation of theory can be done are conceived.

First, empirical analysis, foremost field and laboratory studies, can be employed in order to falsify (in the spirit of Lakatos and Popper (Hausman, 2013; Backhouse, 2012)), and more ambitiously to validate, theoretically derived hypotheses. Whereas field studies have the advantage of high external validity, they can be generally challenged on the premise that it is difficult to establish causal effects due to problems of (unobserved) confounding variables and endogeneity. At a fundamental level, this gives rise to doubts whether empirical observations are able to falsify (a fortiori validate) theory at all. These concerns are magnified due to the context-specific nature of field studies and a lack of control over the environment that encompasses investigations. Laboratory experiments may be able to mitigate some of these concerns through systematic variation of treatment conditions, randomization of subjects and augmented control of the researcher. Based on a high internal validity, although at the cost of lack of external validity, isolation of causal relationships is facilitated and falsification of theoretical propositions is more easily justifiable (Guala, 2005). Furthermore, laboratory experiments facilitate the process of de-idealization (Morgan and Knuuttila, 2012), i.e., the generalization of the model context beyond its well-defined assumptions by successively relaxing the assumptions until the theory's established hypotheses begin to break down. Ultimately, however, laboratory and field studies are complementary means to a similar end.

Second, empirical analysis can evaluate the accuracy of theory-driven predictions over time. Although hypotheses may also be regarded as model predictions, the focus here lies less on falsification of suggested causal relationships, but more on the correct qualitative assessment of the impact of future scenarios. With regard to its ability to predict future states of reality (in the sense of Friedman, 1953), a microfounded theory draws from its ability to explain observations at the macro level, based on an understanding of the underlying mechanisms and the necessary conditions. By this means, theory-driven predictions are likely to be more robust to changes of real systems as underlying causes can be identified and theory can be modified accordingly (Dasgupta, 2002). Moreover, formal analysis allows for experimentation and evaluation of counterfactuals. Two remarks should be made in this context: First, it must be noted that there exists an inherent trade-off between a theory's simplicity and its predictive accuracy. While a simple model or theory may apply more generally and is able to make more robust *qualitative* predictions, it will also almost certainly be too simple to make accurate *quan-*

*titative* predictions. In turn, the reverse holds true for complex models. This is akin to what is known as the bias-variance-trade-off in statistics (cf. Hastie et al., 2009). Second, even if a theory's prediction may be accurate, this does not "prove" in a deductive sense that it is valid. One may only apply what is known as abductive inference here, that is one can infer that a theory was sufficient to predict the phenomenon of interest, but not that it was necessary, i.e., the only possible theory to be sufficient.

Third, and particularly relevant for this thesis, empirical studies can serve as a testbed for theory-driven design proposals. In this context, laboratory experiments can be seen as an intermediate economic engineering step, similar to a wind tunnel in traditional engineering, where the design proposals (e.g., a proposed market design or regulatory institution) can be evaluated under idealized conditions that mirror those assumptions under which the theory was developed. If the proposed design performs well (relative to the intended goal) in the laboratory then it should be taken to the field for further evaluation. If, however, the proposed design already fails to perform in the laboratory, then there is little reason to believe that it would perform well in the field (Plott, 1987). Consequently, the design, and most probably also the underlying theory, would need revision already at this stage.

### 3.1.4 Discussion

Several scholars in the fields of management (Locke, 2007; Hambrick, 2007) and IS (Avison and Malaurent, 2014), among others, have criticized excessive adherence to theory and argue that a scientific contribution can also be made without the need for theory. Whereas this raises important issues with regard to the research process and scientific institutions that are necessary to develop theory, these views still can be reconciled with the belief that the development of robust theories is at the core of scientific endeavour. Above and beyond, the arguments set out above suggest that these models and theories should be both, i) well grounded in stylized empirical facts that are the result of inductive research efforts, as well as ii) evaluated and refined through empirical analyses based on field studies and laboratory experiments. To this end, a microeconomically founded IS research process ideal that is deemed suitable to develop theories that are rigor and relevant has been motivated and discussed. In this spirit, the long term goal of microeconomically founded IS research is the development of robust and stable theories that have been established and refined through several repetitions of the depicted research process cycle.

## 3.2 Theoretical modeling and experimental evaluation

Technological innovations, new business models, and adjusted policy objectives have significant effects on firms' strategic incentives, on the market structure, and thus on the competitiveness of markets as outlined in the preceding chapters. In consequence, established grounds for ex ante regulation and ex post competition policy may no longer be justified. Thus, sector-specific rules such as in the telecommunications industry need to be repeatedly evaluated and adjusted accordingly (see the current review of the European framework by the European Commission, 2016c). Similarly, competition policy, which closely interacts with the regulatory regime specifically in the case of merger control and antitrust, needs to adjust to a changing environment. Although competition authorities decide on a case-by-case basis, investigations and verdicts follow general policy objectives, assumptions, and procedures, which are explicitly codified in guidelines or implicitly given by the history of previous decisions (for evidence that decisions are not exclusively determined by case-specific facts and considerations see, e.g., McGowan and Cini, 1999; Duso et al., 2007). Therefore, both regulatory and competition authorities require systematic and robust evidence on the effects that result from these changes under specific market characteristics and alternative institutions.

Authorities, assigned with the task to identify and design new regulatory mechanisms in the light of these environmental changes, face significant challenges. On the one hand, they have to assess the impact of changing external conditions, while also taking into account the probability of further change. Thereby, the effects of external factors may not always be easily inferred from the observed outcomes in practice, because these effects likely interact with the current policy framework. On the other hand, regulatory mechanisms—designated to address the new circumstances—may be untested, as they have just become available due to technological innovation (see for example the Layer 2 bitstream access product for cable networks standardized by the Bundesnetzagentur, 2013b) or fundamental changes in the market structure. Even if institutions have already been implemented in other contexts, e.g., in another geographical region, it is often unclear whether implications transfer to the considered scenario of interest. In summary, high uncertainty together with high societal costs in case of a failed implementation call for the theoretical investigation and the controlled assessment of such policy proposals and regulatory institutions prior to the implementation in the field. In this vein and in the spirit of Section 3.1, analytic modeling and experimental evaluation are proposed as the primary research methods in this thesis to examine the performance of alternative regulatory institutions under varying market structures and different market characteristics.

Based on the proposed research process ideal, this section first expands on why analytic (game-theoretic) models are well suited to address the research questions in this thesis. Therefore, on the basis of Morgan and Morrison (1999) and Morgan (2002, 2005), the following four functions of models in the context of theoretical and experimental analyses are discussed: 1) *models as representations*, 2) *experimentation on models*, 3) *theory testing*, and 4) *experiments with models*. Subsequently, the use and advancement of models in this thesis is outlined. Finally, the shortcomings of a purely theoretical model-based approach are highlighted and it is discussed how those issues may be resolved by complementary experimental analyses.

**1) Models as representations and a collection of stylized facts** Whereas new models may also be deduced based on theoretical considerations exclusively (Friedman, 1953; Wong, 1973), this thesis is concerned with the design and evaluation of institutions in an applied context. Therefore, models as mediators (Morgan and Morrison, 1999, Chapter 2) combine theory, i.e., the existing body of knowledge, with empirical regularities (stylized facts), i.e., observations of reality. In consequence, a model implicitly represents the decisions about what is deemed relevant about a particular delineated aspect of reality from a theoretical point of view. As mentioned in the previous Section, this gives rise to the trade-off between representational accuracy and generality, but in practice also tractability (Lawson, 2008). Whether the model adequately captures and thus represents the relevant characteristics of reality in its assumptions critically determines the power of *back inference*, i.e. whether results and implications from a model carry over to reality (Morgan, 2002).

**2) Experimentation *on* models** Morgan (2005) characterizes models as autonomous instruments of investigation that allow for *experimentation*. In this vein, "modeling work is creative and exploratory" (Morgan, 2002, p.50) as a model based on a set of axioms and assumptions can be examined with respect to its attributes and interior mechanics, the outcomes and solutions that can be derived, and its generality and limits. Thus, the manipulation of economic models—representing a set of stylized facts of the status quo—allows to assess modifications of established institutions theoretically and to compare hypothetical counterfactuals. The creation of an artificial world and its analysis (Morgan, 2002) constitutes a basis to address research questions even if no empirical basis is available. However, the (external) validity of the obtained results and inference from the model hinges critically on the *realism* of the assumptions that are most relevant to the investigated scenario. As argued above, the representativeness of a model can thus have direct ramifications for the epistemic power of its deduced results, emphasizing the importance of aligning a model's assumptions with empirical stylized facts.

**3) Empirical theory testing on a model basis** Given the research process ideal outlined in Section 3.1, the validity of a model's assumptions and the robustness of its results are subject to empirical evaluation. Economic laboratory experiments allow for a high degree of control regarding the variation of treatment variables and the randomization of influencing (confounding) factors, which yields a high internal validity

(Guala, 2005). Hence, experiments are well suited to provide a first test on whether the model's hypotheses hold under the stated assumptions if they are transferred from an artificial world to a *domesticated* version of reality (Harré, 2003). Furthermore, the experimental design allows to test the robustness of insights and to isolate the causal factors that yield a particular result by incremental and factorial treatment comparisons. Moreover, experimental studies are able to quantify effect sizes and trade-offs, which is often infeasible based on purely theoretical work with abstract models. Obviously, the specification of the experimental design and the transformation of an abstract model into an operational format require parameterization, i.e., a de-idealization of the underlying generalizing assumptions (Morgan and Knuuttila, 2012). Thus, the design of an experiment offers a considerable degree of freedom over and beyond the underlying model specification. Naturally, these specific design decisions limit the theory test to a narrower application scenario than that for the abstract model, which in turn may question the robustness of the findings of an individual study. In combination with concerns regarding the validity of statistical assessments, this has raised momentum for replication studies and meta-studies in several scientific disciplines (see Chapter 8 for a concluding discussion). In this vein, Chapter 6 conducts a meta-study of number effects on the competitiveness in oligopolistic markets which integrates individual studies that are based on different model assumptions. On the contrary, degrees of freedom with respect to the parametrization of an experimental design can be exploited to control for behavioral effects, which are considered out of scope for the particular test of theory. For example, all experimental studies in this thesis parameterize the underlying competition model in a way that participants face identical graphical interfaces across treatments in order to avoid behavioral framing effects.

**4) Experiments *with* models** Analytic models may be employed as experimental instruments even when the model itself is not the object of investigation (Morgan, 2002). Thereby, some outcome or process of an experiment is realized by the instantiation of a theoretical model instead of the controlled interaction between experimental subjects. For instance, in an experimental market subjects may only represent sellers, whereas demand is computed based on a theoretical model of a representative consumer that reacts to the sellers' offers. Here, behavior and outcome is controlled by the model's assumptions instead of experimental variation (Morgan, 2002). Hence, experiments with models may be particularly useful if the investigated scenario is characterized by high complexity, and thus experimental control would be difficult to ensure. In this vein, all experimental studies in this thesis employ stylized competition models as experimental instruments and thus explicitly abstract from details of real transaction processes.

### Use and advancement of models in this thesis

Based on these diverse functions, this thesis draws on oligopoly theory and employs established models of strategic price and quantity competition to investigate the research questions of interest. Theoretical analyses in Chapter 4 and Chapter 5 examine access relationships based on a model of vertically related upstream and downstream markets, building on the recent literature on wholesale competition (Bourreau et al., 2011, 2015; Höffler and Schmidt, 2008). In these models, the retail demand structure is based on the representative consumer suggested by Shubik and Levitan (1980), whereas homogenous Bertrand competition is employed at the upstream level. Exploring these models analytically (in the sense of Morgan, 2005), this thesis adds to the theoretical body of knowledge by analyzing Open Access regulation regimes under infrastructure and wholesale competition. The models' theoretical equilibrium predictions with respect to wholesale competition and open access regulation are then tested experimentally (Chapter 5). Experimental analyses of oligopoly competition in Section 3.3 and Chapter 6 employ models as experimental instruments and exploit the duality of the theoretical demand model proposed by Singh and Vives (1984). To this end, the experimental studies build on the model's generality, its well-known theoretical predictions and its previous application in numerous theoretic analyses (inter alia López and Naylor, 2004; Garella and Petrakis, 2008) as well as in an experimental meta-study (Suetens and Potters, 2007).

Whereas the theory on oligopolistic competition in one-sided markets is fairly mature due to its long history and central role in economic literature, theory-building in the context of digital media and services markets is still in a relatively early stage, although advancing quickly in the recent decade. In particular, competition between online content platforms is likely to be multi-sided (Rochet and Tirole, 2006; Armstrong, 2006; Hagiu and Wright, 2015) due to the presence of indirect network effects (cf. Parker and Van Alstyne, 2005) and users' ability to multi-home, i.e., to use services of different providers at the same time (cf. Choi and Kim, 2010). These characteristics are especially relevant for the competition between online content providers that monetize users' eyeballs through advertising (Evans, 2008). Although there is a rich theoretical literature on advertising competition in offline markets (see, among others, Anderson and Coate, 2005), there is currently no model framework for online advertising competition that easily relates online advertising prices and publishers' ability to track and target consumers. Thus, Chapter 7 offers a theoretical microfoundation for this scenario based on stylized empirical facts and thereby proposes a new model building block to the growing theoretical literature on the competitive effects of data collection and data analysis in online markets (see, e.g., Athey and Gans, 2010; Asdemir et al., 2012; Athey et al., 2014; Montes et al., 2015).

### Complementary use of models and laboratory experiments in this thesis

As outlined in Section 3.1, theoretical model analysis and empirical evaluation naturally complement each other as research methodologies. Conversely, several issues arise if the analysis is exclusively restricted to a single approach. In this vein, the main shortcomings of game-theoretic solution concepts, which are regularly utilized in the theoretical analysis of strategic settings, are highlighted in the following. First, behavioral aspects that are neglected by conventional (one-shot) equilibrium solution concepts may considerably affect market outcomes. Specifically, tacit collusion, which has been found to significantly affect firm behavior in markets with few competitors (Parker and Röller, 1997; Engel, 2007; Potters and Suetens, 2013) and is deemed a critical factor in the oligopolistic telecommunications markets considered here (cf. BEREC, 2015), is currently only rationalized in an infinitely-repeated game context by mainstream economic theory (see, e.g., Nocke and White, 2007; Normann, 2009). Yet, it is well-known that coordinated behavior is also frequently experienced in experimental oligopoly settings that resemble a finitely-repeated game context (see, e.g., Huck et al., 2004b; Orzen, 2008). Moreover, theoretic analyses may predict a multiplicity of equilibrium outcomes for a given scenario and model (see, e.g., Bourreau et al., 2011, for multiple equilibria in the context of wholesale competition). In such cases, it often remains unknown, which of the identified equilibria is more likely to arise. It is thus infeasible to quantify or at least indicate the probability to arrive at a particular outcome in practice. The equilibrium selection problem may be reduced or solved by introducing additional assumptions. In many cases, however, this would only defer the problem to a preceding stage of the modeling process, because it is still unclear which assumption indeed applies to the context of interest. In fact, it may more generally be even unknown which solution (equilibrium) concept is most adequate in the respective scenario (cf. Binmore, 1987). Furthermore, game-theoretic equilibrium solution concepts per definitionem neglect out-of-equilibrium behavior as part of a possible outcome, which may considerably impact strategic behavior and outcome in actual market practice (cf. Arthur, 2006). Although there are theoretical concepts to test the robustness of equilibrium outcomes, such as trembling-hand equilibria (Selten, 1975) and quantal response equilibria (McKelvey and Palfrey, 1995), these concepts in turn require additional assumptions about such behavior. In summary and more abstract terms, the listed issues stem from one of the main advantages of theoretical models as artificial worlds: the explicit and total control over the assumptions. Either these must be explicitly and completely specified a priori or the model may abstract from specific issues entirely, but there is never a "theoretical" approach to let them be determined implicitly.

In contrast, laboratory experiments that provide the "potential for independent action" (Morgan, 2005, p.325) due to a controlled "degree of freedom on the part of participants" (Morgan, 2005, p.325) can leave assumptions unspecified and let them be determined implicitly in the experiment. On this basis, Harré (2003) argues that experiments allow for stronger back inference. In turn, this leads Morgan (2005) to argue that economic experiments exhibit greater epistemic power than theoretical models, because experiments may yield "results that may be unexplainable within existing theory" (p.317). According to this view, experiments may not only falsify theory or provide empirical support, but may represent—like theoretical modeling—an "explorative creative activity" (Morgan, 2005, p.318), which yields unexpected observations that enable the conceptualization of new theories. Moreover, laboratory experiments as a complementary methodology can be exploited to refine theoretical predictions, especially in the case of multiple equilibria (cf. Abbink and Brandts, 2008). Laboratory experiments according to this understanding may thus serve two purposes within the idealized research process cycle (cf. Figure 3.1): Empirical validation or falsification of theoretical hypotheses as well as observation of (isolated) empirical regularities, which inform the formulation of new or refined theories.

Laboratory experiments are at the core of scientific endeavor, most notably in the physical and life sciences. In comparison, economic laboratory experiments have emerged relatively late, but their role and adoption have significantly grown over the recent decades (Falk and Heckman, 2009). Due to high internal validity (Guala, 2005), they are well suited to identify systemic effects and to isolate and measure their causal determinants through controlled variation of exogenous variables. Firm and oligopoly experiments, as surveyed by Potters and Suetens (2013), have therefore been established as an important research approach to test theoretical predictions and to collect observations on empirical regularities in the context of strategic competitive interaction. Moreover, laboratory experiments are utilized to examine the policy implications of institutions which may have not (yet) been implemented in the field and to benchmark the results against designed counterfactuals (see Normann and Ricciuti, 2009, for a survey of laboratory experiments that address economic policy issues). In this spirit, the experimental studies in this thesis make use of the freedom with regard to the *experimental design* as well as with regard to *experimental behavior* of participants to address the research agenda outlined in Chapter 1. In particular with regard to the issue of tacit collusion, which is notoriously hard to detect in field studies, laboratory experiments can provide insights by analyzing in- and out-of-equilibrium strategies and respective market outcomes relative to benchmark equilibria predicted by economic theory. In this vein, economic laboratory experiments may be seen as a cost-efficient testbed for the evaluation of theoretical hypotheses and the comparison of alternative mechanisms, which is particularly relevant in the context of regulatory institutions.

Whereas theoretical models may suffer from "problems of realism" (Morgan, 2005, p.321), experiments may lack *external validity*, i.e., it remains unclear whether the experimental results apply beyond the laboratory context in the relevant domain of investigation (see Schram, 2005, for a discussion). Despite findings that offer support for the external validity of economic experiments with student subjects (Ball and Cech, 1996), there remain concerns particularly with respect to laboratory experiments that study strategies and behavior at the firm level. Most commonly, critics suppose that laboratory experiments are not able to capture the complexity of "real markets". Instead, empirical evaluation should be carried out immediately in the field. However, as pointed out before, there often may exist no field implementation with regard to the issues addressed by this thesis. Moreover, field studies face several challenges themselves with regard to the generalizability of findings and endogeneity concerns as further discussed in Section 6.1. In fact, the lack of control and randomization in many conventional field studies have introduced the experimental design as a desired benchmark and led to the emergence of empirical studies that exploit quasi-experiments (Angrist and Pischke, 2010). In summary, these issues highlight the complementary nature of empirical evaluation methods in contrast to the notion of a unique gold standard. In the interest of robust theory-building it therefore seems valuable to employ heterogenous empirical methods, which each may examine different aspects of a theoretical prediction. In this vein, methodological limitations together with the implications for future empirical work for each individual study will be provided in the respective chapters. Finally, concerns regarding the external validity of laboratory experiments are further addressed by a validation study in Chapter 5, which replicates an experimental treatment with expert subjects and compares results to the student sample.

In a further effort to foster external validity and to facilitate decision making in complex strategic settings, the study on wholesale competition in Chapter 5 employs an experimental framework in continuous time. In contrast to the vast majority of oligopoly experiments, which have employed experiments in discrete time, a continuous time framework does not prescribe any exogenous timing order nor the number of actions that can be undertaken by the subjects. In the spirit of Morgan (2005), this design feature is believed to foster epistemic power because it endogenizes the decision over the timing of actions and thus extends the degree of freedom for subject behavior. By abstaining from a fixed timing structure, experiments in continuous time are able to test the underlying theoretical model's assumptions of a specific timing structure. Moreover, by allowing for continuous decision making and thus the freedom to constantly observe, revise and adapt decisions, subjects' task to understand and act in complex experimental settings is arguably facilitated. Discrete time frameworks inherently restrict the number of actions and often employ only a relatively low number of periods, which may lead to findings that rather resemble laboratory artifacts than stable long-term behavior (see, e.g., Friedman et al., 2015; Oechssler et al., 2016, for a comparison of short-term and long-term experiment horizons in a discrete setting). In contrast, continuous time frameworks do not constrain the number of decisions and may thus also encourage exploratory strategies. This may be of particular importance if theoretical models predict a multiplicity of equilibria and the experimental design needs to ensure that all equilibria are in fact discovered by the subjects.

Despite these advantages, there may be concerns that the design of experiments in continuous instead of discrete time may significantly affect subjects' behavior and thus influence experimental findings in an unknown direction. Yet, only few studies have investigated the effect of an experimental real-time setting that runs continuously and in which players, per definitionem, hold onto their actions until they change them explicitly. Comparative studies have been conducted in the context of prisoner's dilemma games (Bigoni et al., 2015; Friedman and Oprea, 2012) as well as in a Hotelling (1929) location model (Kephart and Friedman, 2015; Kephart and Rose, 2015). However, no systematic investigation on the effect of continuous versus discrete time framing on price and quantity competition in oligopoly experiments exists to date. Therefore, the following section scrutinizes whether prices and profits differ in discrete and continuous time competition, i.e., whether one of the two time frameworks facilitates cooperation and the ability to tacitly collude relative to the other.

## 3.3 Oligopoly competition in continuous time

Decision-making is, by its nature, a continuous process. Individuals but also organizations monitor their environment continuously and may act or react according to their observations at any time. Especially in electronic markets, e.g., online retail or financial markets, sellers and buyers may react promptly to decisions by other market participants. However, the reaction time by decision makers can also be chosen strategically (e.g., strategically delayed), or actions may be taken only for a very short period (e.g., to send a "signal" to the competitor or to retaliate a competitor's action). In continuous time, the reaction time or duration of an action is chosen endogenously by the decision makers and thus offers a richer set of strategies than if actions can only be taken at fixed points in time.

However, most economic laboratory experiments have so far employed a discrete time framework and have thus relied on the assumption that players move simultaneously or sequentially in a pre-defined and ordered sequence. Consequently, subjects in the experiment have a given (limited or infinite) amount of time to decide on their actions. By this means, these experiments abstract from the decision makers' choice with regard to the timing of an action and thus implicitly restrict the space of potential strategies. This study examines the effects when the restrictions imposed by a discrete time framework are removed and decision making is allowed to take place in a continuous time framework. Thereby, this study makes the following two contributions to the literature: First, it provides an examination of non-cooperative game settings in continuous time, a time framework that captures more elements of reality than discrete time but

This section is based on joint work with Niklas Horstmann and Jan Krämer (Horstmann et al., 2015).

for which theoretical predictions are scarce and ambiguous. Second, it is tested empirically whether the degree of tacit collusion differs between experiments in discrete and continuous time. By doing so, the results may inform future experimental designs as well as the appraisal of previous findings from discrete time experiments on oligopoly competition.

Taken to the laboratory, continuous time implies that the length of a period in the repeated game is so small that subjects cannot observe distinct periods, i.e., the reaction time of the experimental software is lower than the human reaction time. In the context of oligopoly competition, a continuous time framework thus allows subjects to set and change prices freely at any time (asynchronous-move), whereas a discrete time setting requires subjects to decide about prices at fixed points in time (synchronous-move). This study is not the first to employ a non-discrete time framework and previous comparisons of discrete and continuous time in lab experiments have been conducted for specific contexts (see Subsection 3.3.1 for an overview). However, it is the first experimental study concerned with the emergence of tacit collusion under oligopolistic competition in continuous time and the first to systematically investigate the differences in outcomes between continuous and discrete time oligopoly experiments. In summary, the findings suggest, irrespective of the underlying competition model (Bertrand or Cournot) and the number of firms (two or three), that firms can coordinate better on collusive outcomes in discrete time oligopoly experiments than in continuous time oligopoly experiments. This is in sharp contrast to the experimental study by Friedman and Oprea (2012), who find higher levels of coordination in continuous time (repeated) than discrete time (one-shot) prisoner's dilemma games. In conclusion, the nature of the game seems to be particularly relevant for whether a continuous or discrete time setting facilitates cooperative behavior.

The remainder of this section is organized as follows. In Subsection 3.3.1, the extant literature on (near-)continuous time experiments is reviewed and a framework to classify different experimental time frameworks is offered. Subsection 3.3.2 describes the design and procedures of the conducted experiment in detail. Empirical results of the laboratory experiment are derived in Subsection 3.3.3. Finally, Subsection 3.3.4 discusses methodological and policy implications of the experimental findings.

### 3.3.1 Timing in experiments

Economic laboratory experiments are used to evaluate theoretical predictions or to assess the implications of economic market designs prior to their application in the field. For this purpose, human participants face repeated decisions in a given experimental scenario. In experiments that study competition between firms, repetition is usually implemented as a (fixed or random) number of successive (and otherwise independent) periods. A period does not start before all subjects have made a decision in the previous period. This yields synchronous (simultaneous) decision-making by the firms, which however does not resemble most strategic interactions in reality such as competition between firms in a market. Instead, firms may make decisions about their products and prices at any given time and respond to their rivals' actions accordingly, i.e., decisions are asynchronous. In consequence, experimental economists may often apply a discrete time framework to model situations in which decisions are actually made in continuous time.

Since the computerization of economic lab experiments, researchers have implemented different timing schemes. However, there is little—although recently growing—evidence on how decision-making in the lab differs between experimental setups in discrete and continuous time (Berninghaus et al., 2007; Friedman and Oprea, 2012; Oprea et al., 2014; Kephart and Friedman, 2015; Kephart and Rose, 2015). In lack of a consistent definition, it is unclear which aspects constitute a discrete time framework and consequently, non-discrete time frameworks in economic lab experiments. Therefore, a classification of discrete and non-discrete time experiments is proposed, before the extant literature is reviewed.

**A classification for continuous and discrete time experiments**

First, it is defined what is commonly meant by a *discrete time experiment*: discrete time is a synchronous-move repeated games framework with an unbounded period length. A period, i.e., a discrete time step, ends only after all subjects have confirmed their decisions. All experimental modes that deviate from this set-up are classified as experiments in non-discrete time and are reviewed subsequently. Among the non-discrete time experiments there exists a variety of modes that can be distinguished further.

The classification of non-discrete time experiments into continuous time and near-continuous time experiments is motivated by Freeman and Ambady (2010), who show that the human reaction time for very simple computerized tasks as measured by the time needed to process information presented on the screen and to perform a mouse click is above 0.5 seconds. Thus, in the most conservative way, *continuous time experiments* are defined as those with rapidly repeated periods (of fixed time length), in which the length of each period is below the threshold of the human reaction time, i.e., 0.5 seconds or below. Technically speaking, as computers are designed to perform operations in discrete steps, a computerized experiment is said to run in continuous time if the transaction time (period length) between the experimental server and the clients is smaller than the subjects' reaction time. In continuous time experiments an action becomes profit-relevant instantaneously and can be observed by other subjects accordingly. Thus, the (potential) consequences of an action cannot be tested prior to making the decision. Moreover, it is virtually impossible for subjects to make decisions simultaneously. Consequently, in continuous time experiments the order or time of decision-making is not exogenously given and thus, inter-period asynchronous interaction emerges naturally. Subjects can act and react upon each others' moves at a self-specified time. Profits and other outcome variables become flow values. Thus, the key aspect of a continuous time framework is that it endogenizes the timing of decisions and thereby captures asynchronicity in decision-making as in many real-world strategic interactions, i.e., decision-making that is neither simultaneous nor sequential.

Continuous time experiments need to be distinguished from *near-continuous time experiments*, which employ a synchronous-move repeated games framework with constant, finite period lengths above the human reaction time, during which subjects have to decide on their action in the subsequent period. As in continuous time experiments, individual decisions are transferred from one period to the next, and hence, "doing nothing" results in choosing the same action as before. Without communication between subjects, decisions by rivals do not become public and profit-relevant before the end of a period. Therefore, as the reaction time is above the human decision threshold, interaction is potentially synchronized and decision-making is simultaneous. Hence, as under discrete time, inter-period asynchronous interaction or even sequential-moving may occur behaviorally, but not naturally.

The advantages of near-continuous time in comparison to discrete time experiments are a high control over the length of the session and the possibility to collect a large amount of data in relatively short time. Thereby, patterns of repeated decisions may occur that would not have been observable in a discrete time experiment (with fewer periods). However, this time framework also bears two potential problems. First, different cognitive and physical abilities of human participants may have a greater influence on experimental results than in an experiment run in discrete time, i.e., some subjects may not be able to change actions fast enough and hence, data on intended decisions would be lost. Second, the repetition of short periods with a fixed length may induce an aspiration to "use the time given" and change one's decision every period. Both caveats generally apply to continuous time experiments as well. However, since profit is a flow value in continuous time experiments, a small difference in subjects' reaction times has only a relatively small impact on profits as subjects can react promptly to a rival's decision. For example, in a duopoly the additional profit gained by defecting from a cooperative state is linear in the rival's reaction time with a continuous time framework but step-wise constant with a near-continuous time framework. Consequently, for the same rival's reaction time below the near-continuous period length, (myopic) profits from defection are higher in near-continuous than in continuous time.

A potential problem of the continuous time framework is that the theoretical prediction of the repeated game may change due to its dynamic nature (see Subsection 3.3.2).

Finally, the continuous time framework needs to be distinguished from a *clock or deadline mechanism*, which is a synchronous-move repeated games framework with constant, finite period lengths under which subjects' current actions are common knowledge and may be changed (freely), but do not become binding, until a clock runs out or a deadline is reached. The action chosen in the very last moment before the end of the deadline is reached becomes binding and constitutes the subject's profit-relevant decision for the next period. Consequently, the current action of a subject may be interpreted as an intention for the final decision in the period but is profit-irrelevant, and thus, cheap talk. Subjects can react to each others' actions during a period, which can be referred to as intra-period asynchronous interaction. As Roth (1995) points out, this experimental design gives some indication of how "last-minute agreements" (p.324) in negotiations evolve.[2] With respect to experimental design, the clock or deadline mechanism is a hybrid of the continuous time framework and the near-continuous time framework. Whereas intra-period interaction between subjects (i.e., cheap talk before the deadline) is asynchronous, inter-period interaction between subjects (i.e., decision-making at the deadline) is synchronized. See Roth (1995) for an overview on the effects of the clock or deadline mechanism and proposed models to explain these effects.

#### Review of non-discrete time experiments

Table 3.1 lists non-discrete time experiments in the extant literature and classifies them according to the definitions given above. Next to the type of game that was run in the laboratory, the length of a period, the mode of asynchronous interaction (i.e., between

[2] There are two further strands of experiments that implement a variant of this clock or deadline mechanism. The first strand (Dorsey, 1992; Goren et al., 2003; Ishii and Kurzban, 2008) introduces restrictions on how actions may be adjusted during the period, e.g., individual contributions in a public good game may only be increased but not decreased over time. Kurzban et al. (2001) compares public good experiments in a clock framework with and without revocable contributions. In the second strand (Levati and Neugebauer, 2004; Murphy et al., 2006), prior to a clock running out, the period may end by other means such as a player dropping out of an auction or exiting a market. Both strands may be viewed as extensions to the basic clock/deadline mechanism.

or within a period) and the classification to one of the non-discrete time frameworks are reported for each experimental study. In the following, a period in the context of repeated games is denoted as the amount of time a subject has to decide on a binding action. Note that this is identical to the minimum amount of time that a binding decision by a subject holds. Thus, a supergame is defined as a complete sequence of a fixed or random number of periods.

Feeley et al. (1997), Berninghaus and Ehrhart (2003), and Berninghaus et al. (1999, 2006, 2007) were among the first to conduct continuous time experiments with period lengths below the human reaction time and a fixed supergame length of several minutes up to half an hour.[3] More recently, Cheung and Friedman (2009), Friedman and Oprea (2012), Oprea et al. (2014), Bigoni et al. (2015), Kephart and Friedman (2015), and Kephart and Rose (2015) ran experiments in continuous time with supergame lengths from 20 seconds to four minutes. Berninghaus and Ehrhart (1998), Deck and Wilson (2002, 2003, 2008), Davis (2009), Davis and Korenok (2009), Davis et al. (2009, 2010), and Friedman et al. (2015) conduct near-continuous time experiments with a high number of rapidly repeated periods. The clock or deadline framework is employed by Roth et al. (1988), Güth et al. (2002), Goren et al. (2004), and Deck and Nikiforakis (2012).

Of the continuous time experiments, only Berninghaus et al. (2007), Friedman and Oprea (2012), Oprea et al. (2014), Kephart and Friedman (2015), and Kephart and Rose (2015) compare outcomes under both discrete and continuous time. Berninghaus et al. (2007) study network formation and network effects in social and economic networks in which connections to other players are beneficial but costly. They find that the formation of a certain star structure, which is the unique Nash equilibrium, prevails under both time frameworks. However, subjects are found to alternate the coveted position of the center player in the star network in continuous time but not in discrete time. Berninghaus et al. (2007) suggest that their results may be explained by inequity aversion. As the discrete treatment is composed of only 15 periods whereas the continuous

[3] Note that Millner et al. (1990) already followed a continuous time approach with output variables given as flow values. However, technical constraints of the PLATO software used for the computerization of the experiment resulted in a transaction time between clients and server of about five seconds, which lies one order of magnitude above the suggested threshold of 0.5 seconds.

TABLE 3.1: *Economic laboratory experiments in non-discrete time.*

| Study | Type of game | Period length† | Async. interaction |
|---|---|---|---|
| | | **Continuous time** | |
| Feeley et al. (1997) | Prisoner's dilemma | n/a†† | Inter-period |
| Berninghaus et al. (1999) | Population | 1/10 seconds | Inter-period |
| Berninghaus and Ehrhart (2003) | Evolutionary | 1/10 seconds | Inter-period |
| Berninghaus et al. (2006) | Network formation | 1/10 seconds | Inter-period |
| Berninghaus et al. (2007) | Network formation | 1/5 seconds | Inter-period |
| Cheung and Friedman (2009) | Coordination | 1/2 seconds | Inter-period |
| Knigge and Buskens (2010) | Network formation | n/a†† | Inter-period |
| Friedman and Oprea (2012) | Prisoner's dilemma | 1/20 seconds | Inter-period |
| Oprea et al. (2014) | Public good | 1/10 seconds | Inter-period |
| Bigoni et al. (2015) | Prisoner's dilemma | 16/100 seconds | Inter-period |
| Kephart and Friedman (2015) | Hotelling | 1/20 seconds | Inter-period |
| Kephart and Rose (2015) | Hotelling | 1/20 seconds | Inter-period |
| Chapter 5 | Wholesale competition | 1/2 seconds | Inter-period |
| | | **Near-continuous time** | |
| Millner et al. (1990)††† | Posted offer | 5 seconds | Inter-period |
| Berninghaus and Ehrhart (1998) | Public good | 10–90 seconds | Inter-period |
| Deck and Wilson (2002) | Posted offer | 3 seconds | Inter-*k*-periods-block |
| Deck and Wilson (2003) | Posted offer | 3 seconds | Inter-20-periods-block |
| Deck and Wilson (2008) | Posted offer | 1.7 seconds | Inter-period |
| Davis (2009) | Posted offer | 7 seconds | Inter-period |
| Davis and Korenok (2009) | Posted offer | 7–70 seconds | Inter-period |
| Davis et al. (2009) | Posted offer | 12 seconds | Inter-period |
| Davis et al. (2010) | Posted offer | 12–18 seconds | Inter-period |
| Friedman et al. (2015) | Cournot competition | 4 seconds | Inter-period |
| | | **Clock/deadline mechanism** | |
| Roth et al. (1988) | Bargaining | 9–12 minutes | Intra-period |
| Dorsey (1992) | Public good | 180 seconds | Intra-period |
| Kurzban et al. (2001) | Public good | 90 seconds | Intra-period |
| Güth et al. (2002) | Public good | 3 minutes | Intra-period |
| Goren et al. (2003) | Public good | 60–90 seconds | Intra-period |
| Goren et al. (2004) | Public good | 60–90 seconds | Intra-period |
| Levati and Neugebauer (2004) | Public good | $\leq$ 50 seconds | Intra-period |
| Murphy et al. (2006) | Trust dilemma | $\leq$ 45 seconds | Intra-period |
| Ishii and Kurzban (2008) | Public good | 90 seconds | Intra-period |
| Deck and Nikiforakis (2012) | Minimum-effort | 60 seconds | Intra-period |

† Period length is defined as the minimum time that a binding decision by a subject holds.
†† The transaction time of the software is not stated, but assumed to be below 0.5 seconds.
††† The experiment uses the PLATO software. Period length is determined as its estimated latency.

treatment runs for 30 minutes, subjects may find it easier to equalize payoffs among themselves in the latter.

Recently, Oprea et al. (2014) compared contributions to a public good in discrete time and continuous time over ten minutes. In the continuous time treatments, contributions could be changed in real-time. In the discrete time treatments, subjects decided on their contributions once a minute, i.e., they played ten periods with a fixed length of one minute. In this setup with few discrete periods (of a limited period length), the authors find no differences in contributions between the two time frameworks.

By contrast, Friedman and Oprea (2012) compare cooperative behavior in the prisoner's dilemma in discrete and continuous time and find that the continuous time framework fosters cooperation among the players relative to discrete time. More precisely, the authors compare continuous and discrete variants of the prisoner's dilemma in supergames with a constant length of 60 seconds. In continuous time, they find a median mutual cooperation rate of 90 percent over the supergames' duration. With the duration of each supergame being fixed, the number of periods is decreased to eight in 60 seconds and finally to one in 60 seconds, i.e., a one-shot game.[4] The main finding of the study is that cooperation decreases as the number of periods decreases so that the median rate of mutual cooperation is zero in the one-shot treatments. In other words, cooperation is higher in a continuously repeated prisoner's dilemma than in a one-shot (discrete) prisoner's dilemma. Friedman and Oprea analyze the subjects' individual behavior in the continuous time treatments and identify different strategies. A model of $\epsilon$-equilibria (Radner, 1986; Bergin and MacLeod, 1993) is found to predict their findings very well. A key aspect of their experimental design is "that period lengths and potential payoffs are kept constant across [...] treatments" (Friedman and Oprea, 2012, p.343). However, this is only achieved by implicitly changing two treatment variables in the transition from continuous time to the one-shot (discrete) treatment at the same time. The first treatment variable is obviously the time framework of a repeated game,

[4]Comparably, Berninghaus and Ehrhart (1998) varied the number of periods (10, 30, and 90) in a public good game of a total fixed session length of 15 minutes and found that cooperation increases with the number of repetitions.

i.e., continuous or discrete, and the second treatment variable is the repetition of the game itself, i.e., repeated game or one-shot game.

Both Kephart and Friedman (2015) as well as Kephart and Rose (2015) compare a discrete time and two continuous time variants of the Hotelling (1929) spatial competition model with and without vertical differentiation. Kephart and Friedman (2015) find that under continuous time location choices resemble the static Nash equilibrium more closely than under discrete time. With vertical differentiation and an additional choice on price, Kephart and Rose (2015) find some support for the notion that continuous time increases cooperation. Whereas subjects may decide instantaneously in one of the continuous time treatments, they may change their decision only gradually at a specified "speed" in the other continuous treatment. However, under discrete time, subjects have to decide on location (and price in case of Kephart and Rose, 2015) during a three second time interval. Note that with respect to the timing classifications outlined above, these discrete time treatments clearly fall under the near-continuous time framework.

### 3.3.2 Experimental framework

The following experiment studies the impact of continuous time relative to discrete time on the outcome of experimental oligopoly competition. In an attempt to foster the robustness of findings, symmetric differentiated Bertrand as well as Cournot competition in duopolies and triopolies each are considered. Thereby, the experiment examines three dichotomous treatment variables (discrete vs. continuous time, Bertrand vs. Cournot competition, duopolies vs. triopolies) in a full-factorial design, resulting in a total of eight different treatments. The labels used to refer to the treatments in the following sections are stated in Table 3.2 by appending abbreviations from left to right, e.g., $RB3$ refers to the continuous (real-time) Bertrand triopoly treatment.

TABLE 3.2: *Treatment variables and their values.*

| Time framework | Competition model | Number of firms |
|---|---|---|
| Discrete time (D) | Bertrand (B) | Duopoly (2) |
| Continuous time (real-time) (R) | Cournot (C) | Triopoly (3) |

**Oligopoly competition**

Price competition à la Bertrand and quantity competition à la Cournot are the two workhorse models of IO. When comparing different designs in experiments on firm behavior, they serve as good proxies for a large share of models on oligopoly competition. As homogeneous price competition yields a discontinuous demand function and the empirically observed Bertrand paradox is often deemed unrealistic, the model by Singh and Vives (1984)—which generalizes the Hotelling (1929) model to exploit the duality between price and quantity competition in differentiated goods—is utilized for the experiment. More precisely the model's generalization (Häckner, 2000) to more than two firms is employed (see, e.g., Suetens and Potters, 2007, for a previous application in the context of oligopoly experiments).

Consider a market with $n \in \mathbb{N}$ firms. Each firm $k \in \{1, ..., n\}$ produces a single good. The firms' goods are differentiated horizontally but are homogeneous in vertical quality and have identical demand elasticity. Thus, firms are assumed to be symmetric. Note that asymmetric (inverse) demand may result in additional behavioral effects in the experiment which are not in focus here, but are further analyzed in Chapter 6 in an asymmetric application of the model. In the following, a brief sketch of the propensities of the model is provided, while a detailed analysis of the theoretical predictions is relegated to Appendix A.1.

For the Cournot treatments of quantity competition, the inverse demand for firm $k$ is given by

$$p_k = \omega - \lambda \left( q_k + \theta \sum_{j \neq k} q_j \right)$$

with $\omega, \lambda > 0$ and the degree of substitutability $\theta \in [-1,1]$. If $\theta < 0$ goods are complements, if $\theta = 0$ goods are independent of one another, and if $\theta = 1$ they are perfect substitutes. For non-perfect substitutes ($\theta < 1$), the corresponding demand function for firm $k$ in the Bertrand treatments is given by

$$q_k = \Gamma - \Lambda p_k + \Theta \frac{\sum_{j \neq k} p_j}{n-1}$$

with

$$\begin{aligned}
\Gamma &= \frac{\omega}{\lambda(1+\theta(n-1))}, \\
\Lambda &= \frac{1+\theta(n-2)}{\lambda(1-\theta)(1+\theta(n-1))}, \\
\Theta &= \frac{\theta(n-1)}{\lambda(1-\theta)(1+\theta(n-1))},
\end{aligned}$$

and $n$ as the number of firms with non-negative demand, i.e., firms that have not exited the market due to a too high price. If $q_k < 0$ firm $k$ exits the market, its quantity is set to zero, and $n$ is decreased by one. Normalizing costs to zero, firm $k$'s profit is $\Pi_k = p_k q_k$.

For the subsequent empirical analysis, three benchmark outcomes for Bertrand and Cournot competition are considered, respectively. Note that, although goods are differentiated, equilibrium prices and quantities are the same for all firms. First, under the Walrasian (competitive) equilibrium firms are assumed to be price-takers so that they maximize their profit irrespective of their rivals' decision. Second, the Nash equilibrium assumes that firms choose a price (quantity) such as to maximize their own profit given their rivals' prices (quantities). Third, under the collusive outcome firms are assumed to cooperate and hence, employ joint profit maximization (JPM) acting as a single monopolist. It is straightforward to show that $\Pi^{JPM} \geq \Pi^{Nash}_{Cournot} \geq \Pi^{Nash}_{Bertrand} \geq \Pi^{Walras}$ for all valid parameter combinations. If goods are substitutes ($\gamma > 0$), which will be assumed subsequently, Nash prices and profits are higher under Cournot competition than under Bertrand competition.

TABLE 3.3: *Scaled theoretical benchmarks of oligopoly competition for each treatment as displayed in the experiment.*

| | Bertrand | Cournot |
|---|---|---|
| Duopoly | $p^{Walras} = 0$ | $p^{Walras} = 0$ |
| | $q^{Walras} = 60.00$ | $q^{Walras} = 100.00$ |
| | $\Pi^{Walras} = 0$ | $\Pi^{Walras} = 0$ |
| | $p^{Nash} = 25.00$ | $p^{Nash} = 37.50$ |
| | $q^{Nash} = 45.00$ | $q^{Nash} = 62.50$ |
| | $\Pi^{Nash} = 1406.25$ | $\Pi^{Nash} = 1406.25$ |
| | $p^{JPM} = 50.00$ | $p^{JPM} = 50.00$ |
| | $q^{JPM} = 30.00$ | $q^{JPM} = 50.00$ |
| | $\Pi^{JPM} = 1875.00$ | $\Pi^{JPM} = 1500.00$ |
| Triopoly | $p^{Walras} = 0$ | $p^{Walras} = 0$ |
| | $q^{Walras} = 42.86$ | $q^{Walras} = 100.00$ |
| | $\Pi^{Walras} = 0$ | $\Pi^{Walras} = 0$ |
| | $p^{Nash} = 16.67$ | $p^{Nash} = 30.00$ |
| | $q^{Nash} = 35.71$ | $q^{Nash} = 70.00$ |
| | $\Pi^{Nash} = 1406.25$ | $\Pi^{Nash} = 1406.25$ |
| | $p^{JPM} = 50.00$ | $p^{JPM} = 50.00$ |
| | $q^{JPM} = 21.43$ | $q^{JPM} = 50.00$ |
| | $\Pi^{JPM} = 2531.42$ | $\Pi^{JPM} = 1674.22$ |

For the experiment, the parameters of the oligopoly competition model are $\omega = 100$, $\lambda = 1$, and $\theta = \frac{2}{3}$. Consequently, $\Gamma = \frac{300}{2n+1}$, $\Lambda = \frac{6n-3}{2n+1}$, and $\Theta = \frac{6n-6}{2n+1}$. Table 3.3 shows the corresponding scaled theoretical benchmarks of the one-shot game for each treatment as displayed in the experiment.

In a further effort to maximize comparability between treatments and to prevent any source for behavioral effects other than the treatment, input and output variables are scaled in the following way. The action space of prices in Bertrand treatments and quantities in Cournot treatments is equally set to $[0, 100]$ with a minimum increment of one and the joint profit maximizing action at a price or quantity of 50. This ensures that the collusive action is not more or less "behaviorally attractive" across treatments and that the search costs of finding the collusive action are the same in all treatments. With a similar intention profits are scaled so that they would be equal in Nash equilibrium. Thereby, a subject playing the Nash equilibrium of the one-shot game—given that its competitors play Nash as well—would make identical profits in all treatments. Altogether, this precludes confounding effects of the experimental design and parametrization. Furthermore, perfect information was ensured in all treatments, i.e., subjects got individual feedback about each competitor's price, quantity and profit.

#### Repeated games in discrete time and continuous time

Moving from the one-shot game introduced above to the repeated game implemented in the experiment, several experimental design implications are inferred from the extant literature. First, in contrast to Friedman and Oprea (2012), repeated games are employed in the discrete time treatments as well as in the continuous time treatments. Second, the discrete time treatments are composed of 60 periods—much more than in Berninghaus et al. (2007) or Oprea et al. (2014)—to reduce differences to continuous time solely due to a longer time horizon of the experiment (Friedman et al., 2015; Oechssler et al., 2016). Third and contrasting Kephart and Friedman (2015) as well as Kephart and Rose (2015), in the discrete time treatments the time provided to subjects for their decision-making process in each period is not limited. Fourth, discrete time sessions were ran first and the duration of the continuous time sessions was then set to equal the average duration of the discrete time sessions, which was about 30 minutes. Hence, the total session length is similar across all treatments and one period in discrete time corresponds to 30 seconds in continuous time. The period length in the discrete time treatments is infinite and 0.2 seconds in the continuous time treatments, i.e., considerably below the conservative threshold of 0.5 seconds. Under the continuous time framework, current profit represents a flow value of time. In order to maximize comparability between treatments, the profit displayed in the experimental software is thus scaled to the profit that subjects would earn if the current prices or quantities would be held constant for 30 seconds, ceteris paribus. Thereby, given the same prices or quantities in one of the discrete time treatments and the corresponding continuous time treatment, the information presented to the subjects is not only qualitatively equal but also visually identical.

The model of differentiated Bertrand and Cournot competition considered in this experiment has a unique strict Nash equilibrium in the one-shot (stage) game. In discrete time, this also constitutes the unique subgame perfect equilibrium of the finitely repeated game. In continuous time, however, the theoretical prediction is not straightforward. Maskin and Tirole (1988a,b) consider two different continuous time frameworks with endogenous timing in duopolistic price and quantity competition and show that equilibrium behavior is similar to a sequential-move infinitely repeated duopoly. In particular, continuous time is modeled as a fine grid of periods in a sequential-move game, where firms are committed to a price or quantity for a deterministic or stochastic length of time. Whereas the deterministic variant may rather apply to repeated games that were classified as near-continuous time, the stochastic variant does capture the asynchronous nature of continuous time quite well. Irrespective of the time variant, a collusive equilibrium emerges for discount factors close to one. In their model, Maskin and Tirole assume that the Markov property holds, i.e., that future states of the stochastic process only depend on the current state and not the sequence of states that preceded it. In a comparable fashion, Simon and Stinchcombe (1989) model continuous time as "a discrete time model, but with a grid that is infinitely fine" (p.1171) and thereby suggest a more general definition of games in continuous time. Friedman and Oprea (2012) point out that this model predicts mutual cooperation at all times in a prisoner's dilemma, which may be viewed as a highly abstracted variant of homogeneous Bertrand competition. In sum, theory predicts that, if anything, asynchronous-move continuous time is more prone to tacit collusion than simultaneous-move discrete time. Additionally, Bigoni et al. (2015) find that a deterministic ending rule facilitates cooperation even more than a stochastic ending rule under continuous time, whereas other experimental evidence indicates that the opposite may hold under discrete time (Dal Bó, 2005). Theses findings add further support to the conjecture that the continuous time treatments in this experiment are expected to exhibit more tacit collusion than the discrete time experiments.

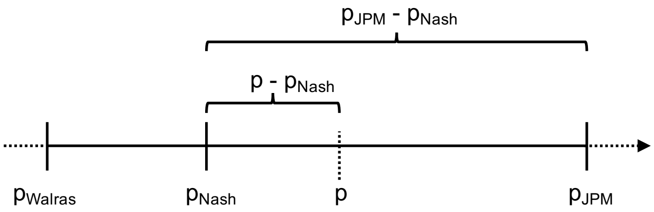
**Measuring the degree of tacit collusion**

As Nash prices, quantities, and profits do not coincide under Bertrand and Cournot and are additionally dependent on the number of competitors, these values are not adequate to compare cooperative intentions, i.e., tacit collusion, across treatments. This study therefore combines indices for the degree of tacit collusion used by Engel (2007) and Suetens and Potters (2007) to compare tacit collusion between treatments irrespective of different theoretical predictions. Thereby, the degree of tacit collusion is measured as the relative deviation of a price, quantity, or profit from the theoretical prediction towards the joint profit maximizing price, quantity, or profit. With respect to Bertrand (Cournot) competition, a price (quantity) set by a firm can be unambiguously converted to a degree of tacit collusion. Hence, for means of comparison between treatments, firms may be assumed to decide on a certain degree of tacit collusion instead of a price or quantity. In a similar fashion, a firm's profit as well as average profit of firms in a market may be expressed as a degree of tacit collusion. Therefore, a degree of tacit collusion based on model input, i.e., price in Bertrand and quantity in Cournot, as well as a degree of tacit collusion based on model output, i.e., profit is considered. Formally, the degree of tacit collusion is

$$\varphi_x^E = \frac{x - x^E}{x^{JPM} - x^E},$$

with $x \in \{p/q, \Pi\}$ and $E \in \{Nash, Walras\}$, resulting in four different measures depending on the theoretical benchmark (Nash or Walrasian equilibrium) and on the input or output variable (price/quantity or profit). Figure 3.2 illustrates the degree of tacit collusion based on prices as measured relative to the Nash equilibrium, given the observed price $p$. If $\varphi_x^E = 0$, the value of $x$ corresponds to the theoretical prediction by the equilibrium concept $E$. If $\varphi_x^E = 1$, the market is completely collusive and competitors behave as a single monopolist. Note that $\varphi_{p/q}^E$ may exceed one as joint profit is not monotonic in price or quantity, but $\varphi_\Pi^E \leq 1$.

FIGURE 3.2: *Normalized degree of tacit collusion based on prices relative to the Nash equilibrium (based on Engel, 2007, p.494).*




**Experimental procedures**

With respect to the technical requirements of continuous time and to ensure high control over the correct scaling of time in all treatments, the experiment was computerized with *Brownie*, a newly-developed *Java*-based experimental software (Müller et al., 2014).[5] All sessions were run at the Karlsruhe Institute of Technology in Karlsruhe, Germany between October and December 2014. First the four discrete time treatments with 60 periods were ran. Without the first period, in which subjects familiarized themselves with the experimental software and decided on their initial price or quantity, the discrete time sessions took on average roughly 30 minutes. This amount of time was used to parametrize the length (again, without the phase of deciding on initial price or quantity) of the subsequently run continuous time sessions. Note that no practice periods with interaction between subjects were run and thus, no learning confounds may occur. The matching of subjects was constant throughout a session (fixed partner matching). In total, 240 students of economic fields participated in the experiment. Subjects were recruited via the ORSEE platform (Greiner, 2015) and participated only in one of the treatments (between-subject design).

The protocol for each session follows five steps. First, upon entering the lab, subjects are randomly assigned to a chair, from which they can neither see nor speak to any other participant of the experiment. Second, after everyone has been seated, the experimental instructions are handed out to the participants in print and read aloud from

[5]Recently, further experimental software that captures continuous time was introduced by Pettit et al. (2014), particularly for experimenters with limited programming skills, and by Hawkins (2015) for web-based experiments.

a recording.[6] The recording ensures that any confounding effect of the reader's voice, accent, or intonation is identical across sessions from the same treatment and as similar as possible across treatments. Therefore, identical paragraphs across treatments are recorded once and the recording is used in all treatments. Third, prior to the beginning of the experiment, each participant has to complete a computerized test of questions regarding the comprehension of the instructions. It is only allowed to proceed to the next question after the correct answer to the current question is entered. Fourth, after all subjects have successfully completed the test, the experiment starts automatically. Over the course of the experiment participants wear ear protectors so that they are not influenced by clicking noises of computer mouses or other disturbing noise. Fifth, following the end of the experiment, each participant is paid out the profits accumulated during the experiment privately and in cash. Following this protocol, the total length of a session from subjects' entering to leaving the lab was about one hour. The average payoff per subject was EUR 16.85.

### 3.3.3 Results

The experimental data amounts to 12 independent duopolies or triopolies in each treatment. Due to no-shows, two exceptions are the *RB*3 treatment for which there are only 11 triopolies and the *RC*3 treatment for which there is data on 13 triopolies, because the number of no-shows required an additional session. For each cohort there is data on market variables over 60 periods in a discrete time treatment and on 9,000 ticks (at an interval of 0.2 seconds each) for each market in a continuous time treatment. In the following the experimental data is first analyzed on the level of independent cohorts, followed by a panel analysis that considers observations at the tick and period level. Table 3.4 reports degrees of tacit collusion across treatments averaged over cohorts and gives a first impression on treatment effects.[7] Most notably, in stark contrast

[6] As an example, the experimental instructions of the *RB*3 treatment together with a screenshot of the experimental software are provided in Appendix C.1.

[7] To reduce distortions by start- and end-game effects, the first and last sixth of periods have been dropped before computing cohort averages. For comparison to Table 3.4, average degrees of tacit collusion over the entire time horizon across treatments are reported in Appendix B.1.

TABLE 3.4: *Average degrees of tacit collusion across treatments.*

| Treatment | Obs. | $\bar{\varphi}_{p/q}^{Nash}$ | $\bar{\varphi}_{\Pi}^{Nash}$ | $\bar{\varphi}_{p/q}^{Walras}$ | $\bar{\varphi}_{\Pi}^{Walras}$ |
|---|---|---|---|---|---|
| DB2 | 12 | 0.860 | 0.861 | 0.930 | 0.965 |
| | | (0.285) | (0.326) | (0.142) | (0.081) |
| DB3 | 12 | 0.659 | 0.683 | 0.773 | 0.859 |
| | | (0.352) | (0.327) | (0.235) | (0.145) |
| DC2 | 12 | 0.674 | 0.532 | 0.918 | 0.971 |
| | | (0.574) | (0.994) | (0.143) | (0.062) |
| DC3 | 12 | 0.473 | 0.364 | 0.789 | 0.898 |
| | | (0.551) | (0.785) | (0.220) | (0.126) |
| RB2 | 12 | 0.769 | 0.736 | 0.885 | 0.934 |
| | | (0.371) | (0.468) | (0.185) | (0.117) |
| RB3 | 11 | 0.555 | 0.505 | 0.703 | 0.780 |
| | | (0.329) | (0.350) | (0.219) | (0.156) |
| RC2 | 12 | 0.842 | 0.760 | 0.960 | 0.985 |
| | | (0.279) | (0.374) | (0.070) | (0.023) |
| RC3 | 13 | 0.424 | 0.233 | 0.770 | 0.877 |
| | | (0.516) | (0.784) | (0.206) | (0.125) |

Standard deviations in parentheses.

to the hypothesis, the degree of tacit collusion based on Nash profits is significantly higher under discrete time than under continuous time in a non-parametric one-tailed Mann-Whitney U test without controlling for the competition model or the number of competitors ($z = 1.77, p = 0.038$).

In order to allow for a comparison of panel data from both time frameworks, the experimental data from the continuous time treatments is mapped to the 60 periods of the discrete time treatments. In particular, for each discrete period, the degree of tacit collusion in the continuous time treatments is averaged over 30 seconds, i.e., 150 consecutive ticks of 0.2 seconds. Thereby, the first 30 seconds correspond to the first discrete period, the next 30 seconds correspond to the second discrete period, and so on. The mean is used as a single proxy for the behavior over 30 seconds as it has the advantage that a maximum of information about the distribution is preserved and that it is, loosely speaking, merely a reduction in data resolution rather than a reduction in data itself. In contrast to the median or other point statistics, changing the value of any single data point inevitably changes the mean as well. For a direct comparison of the two time frameworks using the mean is therefore arguably most conservative.

**RESULT 3.1.** *The degree of tacit collusion based on profits is significantly higher under discrete time than under continuous time.*

A firm's profit is determined not only by its own decisions but also by the decisions of its rivals. One firm's profit in a period is hence not independent from its rivals' profits. Therefore, the degree of tacit collusion based on profits is measured on the market level, i.e., calculating the average of each firm's profit in a duopoly or triopoly. There are a total of 96 markets across all treatments with 60 discretized periods each. Testing for treatment effects in panel data requires to control for the dependence between observations from the same market as opposed to observations from different markets. Consequently, the following multilevel mixed-effects regression model is estimated, for which treatment DB2 serves as a baseline:

$$\begin{aligned}\varphi^{E}_{\Pi,t,m} = \beta_0 + \xi_m \\ &+ \beta_{Continuous} \cdot Continuous \\ &+ \beta_{Cournot} \cdot Cournot \\ &+ \beta_{Triopoly} \cdot Triopoly \\ &+ (\beta_{Period} + \beta_{Period,m}) \cdot t \\ &+ \epsilon_{t,m},\end{aligned}$$

where $\varphi^{E}_{\Pi,t,m}$ is the degree of tacit collusion based on average profit $\Pi$ of all firms on market, i.e., duopoly or triopoly, $m$ in period $t$. On the market level, $\xi_m$ is the random intercept that controls for intra-cluster correlation in terms of different base levels of tacit collusion between markets and $\beta_{Period,m}$ is a random coefficient for the time trend in each market.

Table 3.5 reports estimates for the degree of tacit collusion based on Nash (Model 1) and Walrasian (Model 2) profits, respectively. Irrespective of the theoretical benchmark, continuous time is found to have a significant negative effect on tacit collusion and reduces the degree of tacit collusion between 4 and 20 percentage points (pp), ceteris paribus. This is in stark contrast to the hypothesis and previous experimental findings. Yet, both control treatment dummies for the competition model and the number of firms show the expected effects. In line with the meta-study on number effects in oligopoly experiments in Chapter 6, triopolies exhibit (10 to 22 pp) less tacit collusion than duopolies. Moreover, price competition is found to facilitate tacit collusion compared to quantity competition if measured based on Nash profit. The degree of tacit collusion is almost 26 pp lower under quantity competition compared to price competition. However, the finding is reversed if tacit collusion is measured based on Walrasian profit. Then, the degree of tacit collusion under quantity competition lies almost 5 pp above price competition, everything else being equal. This is also in line with the expectation as the Walrasian equilibrium is independent of the competition model so that the Walrasian-based degree of tacit collusion does not control for the different Nash predictions of price and quantity competition. Furthermore, there are no significant interaction effects between the treatment variables in either regression model. In sum, the effect of continuous time compared to discrete time is not only statistically significant but similar in magnitude to the effects due to the number of competitors and the mode of competition.

In addition to the assessment of collusion degrees based on profits, i.e., an output variable, a similar yet complementary analysis of prices and quantities, i.e., input variables, is conducted next. Thereby, instead of aggregate market behavior, the individual firm choices of prices and quantities are compared across treatments.

**RESULT 3.2.** *The degree of tacit collusion based on prices and quantities is significantly higher under discrete time than under continuous time.*

Each decision by a firm on a price or quantity can be unambiguously transferred into a choice for a certain degree of tacit collusion, which makes decisions on prices and quantities comparable across treatments. Applying the same approach as above, the

TABLE 3.5: *Multilevel mixed-effects linear regressions of the degree of tacit collusion on treatments.*
*Baseline: Discrete Bertrand Duopoly (DB2).*

| Covariate | (1) $\varphi_{\Pi}^{Nash}$ | (2) $\varphi_{\Pi}^{Walras}$ | (3) $\varphi_{p/q}^{Nash}$ | (4) $\varphi_{p/q}^{Walras}$ | (5) $\varphi_{p/q}^{Nash} \leq 1$ | (6) $\varphi_{p/q}^{Walras} \leq 1$ |
|---|---|---|---|---|---|---|
| Continuous | $-0.196^{*}$ | $-0.037^{*}$ | $-0.109^{**}$ | $-0.092^{**}$ | $-0.106^{**}$ | $-0.094^{**}$ |
| | (0.110) | (0.022) | (0.052) | (0.037) | (0.053) | (0.038) |
| Cournot | $-0.264^{**}$ | $0.048^{**}$ | $-0.276^{***}$ | $-0.053$ | $-0.235^{***}$ | $-0.003$ |
| | (0.110) | (0.022) | (0.052) | (0.037) | (0.053) | (0.038) |
| Triopoly | $-0.219^{**}$ | $-0.097^{***}$ | $-0.179^{***}$ | $-0.138^{***}$ | $-0.190^{***}$ | $-0.145^{***}$ |
| | (0.110) | (0.022) | (0.054) | (0.038) | (0.054) | (0.039) |
| Period | $< 0.001$ | $> -0.001$ | $> -0.001$ | $-0.001$ | $< 0.001$ | $< 0.001$ |
| | (0.002) | ($< 0.001$) | (0.001) | ($< 0.001$) | (0.001) | ($< 0.001$) |
| Constant | $0.851^{***}$ | $0.941^{***}$ | $0.914^{***}$ | $0.883^{***}$ | $0.853^{***}$ | $0.823^{***}$ |
| | (0.110) | (0.022) | (0.055) | (0.039) | (0.056) | (0.040) |
| Groups | 96 | 96 | 240 | 240 | 240 | 240 |
| Observations | 5,760 | 5,760 | 14,400 | 14,400 | 13,876 | 13,876 |

Standard errors in parentheses.
$^{*}\ p < 0.10$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$

following multilevel mixed-effects regression model is used to estimate firms' behavior over time as measured by the degree of tacit collusion and to control for firm-specific random effects:

$$\begin{aligned}
\varphi^{E}_{p/q,t,k} = \beta_0 &+ \xi_k \\
&+ \beta_{Continuous} \cdot Continuous \\
&+ \beta_{Cournot} \cdot Cournot \\
&+ \beta_{Triopoly} \cdot Triopoly \\
&+ (\beta_{Period} + \beta_{Period,k}) \cdot t \\
&+ \epsilon_{t,k},
\end{aligned}$$

with $\varphi^{E}_{p/q,t,k}$ as the degree of tacit collusion based on firm $k$'s price $p$ or quantity $q$ played in period $t$.

Estimation results for Models 3 and 4, reported in Table 3.5, confirm that the degree of tacit collusion of firms' actions is significantly higher (9 to 11 pp) under discrete time than under continuous time, both with respect to Nash equilibrium as well as Walrasian equilibrium. Similarly, prices and quantities in triopolies are 14 to 18 pp less collusive than in duopolies. With respect to the mode of competition, however, price competition elicits more collusive behavior than quantity competition irrespective of the underlying theoretical benchmark. Although the difference is found to be significant and economically relevant with almost 28 pp only in the Nash-based degree of tacit collusion, quantity competition is—contrary to expectations—not more prone to tacit collusion based on Walrasian equilibrium. Again, there are no significant interaction effects between treatment variables.

A possible criticism of the previous analysis is that $\varphi^E_{p/q}$ is not monotonic in "collusiveness" as it may exceed one, although firms make lower profit compared to the case of $\varphi^E_{p/q} = 1$. In fact, 3.6% of firms' prices and quantities exceed $x_{JPM}$. However, any value of $\left|\varphi^E_{p/q}\right| < 1$ is a deviation from the collusive equilibrium. This is not captured in Models 3 and 4 in Table 3.5. Excluding all observations with $\varphi^E_{p/q} > 1$ results in estimates reported in Models 5 and 6, which show that the treatment effects are robust to degrees of tacit collusion exceeding one. Other alternatives dealing with these outliers such as folding down all observations with a tacit collusion degree above one, i.e., choosing $1 - \left|1 - \varphi^E_{p/q}\right|$ as the dependent variable, lead to similar results.

### 3.3.4 Discussion

This study provides empirical evidence that tacit collusion is higher in discrete time experimental oligopolies than in continuous time experimental oligopolies. Thereby, discrete time is based on synchronized and simultaneous decision-making and continuous time is based on asynchronous and endogenized decision-making. These findings are robust with respect to a full-factorial treatment design with i) differentiated Bertrand and Cournot competition, ii) in duopolies and triopolies, iii) under discrete time and continuous time. The key insights can be summarized as follows: First, controlling for the competition model as well as the number of firms there is significantly more tacit collusion under discrete time than under continuous time, irrespective of whether the Nash or the Walrasian equilibrium serves as the relative benchmark. This is in stark contrast to the theory (Maskin and Tirole, 1988a,b; Simon and Stinchcombe, 1989) as well as previous experimental studies on continuous and discrete time (Friedman and Oprea, 2012; Oprea et al., 2014). Second, the study confirms two well-known relationships obtained in previous studies: Duopolies are found to be more collusive than triopolies (see Chapter 6); and Bertrand competition in prices is found to be more prone to tacit collusion than Cournot competition in quantities (Suetens and Potters, 2007). These latter findings indicate that participants in the experiment behave in line with the general theory on oligopoly competition and thus findings with respect to the effect of the time framework cannot be simply dismissed as experimental artifacts.

In this vein, the implications for further research are two-fold. First, researchers designing oligopoly experiments should consider that the implementation of a certain time framework may alter their results. In particular, experiments on tacit collusion—which were until now solely run in discrete time—may have potentially overestimated the supra-competitive effect. Furthermore, it cannot be ruled out that the mode of timing interacts with other properties of oligopoly competition such as market demand, cost structure or strategy space. Second and more general, the effect of continuous time on repeated non-cooperative games is ambiguous. In contrast to this study, experiments on simpler games such as contribution to a public good (Oprea et al., 2014) or the prisoner's dilemma (Friedman and Oprea, 2012) found no differences between time frameworks or even higher propensities to cooperate under continuous time than under discrete time. The experiment differs from these two studies in several ways, especially with regard to a greater action space and a higher number of periods in the discrete time treatments. Thus, it may prove worthwhile to systematically vary the number of periods in future research on discrete time versus continuous time and extend the comparison to other games (with a different number of possible actions).

For a deeper understanding of why oligopolistic firms find it easier to tacitly collude under discrete time than under continuous time a more profound analysis of firms' behavior is required. Firms may apply different strategies or learn from past behavior in many different ways: For example, behavior by firms in repeated oligopoly competition may be characterized by a static strategy (see, e.g., Fudenberg et al. (2012) for strategies in a prisoner's dilemma), by a dynamic strategy such as the imitation of a competitor's behavior (Huck et al., 1999) or by learning from own and competitors' decisions in the past (Huck et al., 2004a). In particular, reinforcement learning, which was previously found to converge to collusion in a homogeneous Cournot oligopoly (Waltman and Kaymak, 2008), may be a fruitful approach in explicitly capturing the different dynamics of simultaneous-move discrete time and asynchronous-move continuous time. Furthermore, as continuous time makes simultaneous decision-making virtually impossible, experiments comparing sequential-move and simultaneous-move games may be connected to the findings of this study. In fact, experiments on quantity (Huck et al., 2001) and price (Kübler and Müller, 2002) competition suggest that sequential-move interaction is less prone to tacit collusion than simultaneous-move competition. However, this finding holds only if the sequence of decision-making is exogenous. Instead, if timing of sequential decisions is endogenous, behavior is equal to simultaneous-move oligopolies (Fonseca et al., 2005; Müller, 2006).

A key feature of the presented experimental design is that it compares two extremes of a spectrum of time frameworks with each other: Pure discrete time with no limit on period lengths and pure continuous time with a fixed period length below the human reaction time. Obviously, this design inherently cedes control over the duration of sessions in discrete time. Therefore, a further investigation of period lengths in the transition from discrete time to continuous time may provide valuable insights whether the effect of the time framework is driven by period length, number of repetitions, or the (a)synchronicity of decision-making. In particular, this calls for an experiment in near-continuous time with different period lengths and different numbers of periods.

# Chapter 4

# Infrastructure Competition and Open Access Regulation

MARGIN squeezes can occur in markets where non-integrated downstream firms, which supply only retail goods, rely on wholesale access to an essential upstream good provided by a vertically integrated competitor. In this case, the integrated firm may be able to set the wholesale price above the retail price, i.e., to *squeeze the margin* of the downstream firm, and thus to ultimately induce its exit from the retail market, i.e., to *foreclose* the non-integrated rival. Whether regulators or antitrust authorities should intervene in cases of margin squeeze conduct is controversial. European agencies and courts qualify margin squeeze conduct as a stand-alone antitrust abuse (see the cases *Deutsche Telekom*, *Telefónica*, and *TeliaSonera*), whereas US courts dismiss allegations based on the margin squeeze rationale (see the cases *linkLine* and *Trinko*). Auf'mkolk (2012) reviews recent margin squeeze cases in competition law, Gaudin and Saavedra (2014) discuss margin squeeze regulation in European telecommunications markets.

This chapter scrutinizes Open Access regulation that prohibits margin squeezes in markets with more than one integrated firm producing the upstream good. More specifically, a retail triopoly is considered in which one vertically integrated firm provides

This chapter is based on joint work with Niklas Horstmann and Jan Krämer (Horstmann et al., 2016a).

wholesale access to a non-integrated downstream competitor, while the other integrated firm relies on self-supply of the upstream good and does not offer access. This generic market structure captures any industry in which downstream firms are supplied by a wholesale monopoly while other integrated firms exercise additional competitive pressure in the retail market. In particular, the scenario of *infrastructure competition* in conjunction with retail competition resembles the current state of many European telecommunications markets, where former telecommunications incumbents compete with integrated cable operators as well as with retailers that rely on the incumbent's access network as an input.

The extant economic literature on margin squeeze regulation focuses on market structures with a single integrated monopolist under different settings. First, starting from a setting with homogeneous retail goods, Jullien et al. (2014) point to ambiguous effects of banning margin squeezes: although wholesale prices decrease, retail prices may increase. In other words, non-integrated retailers benefit from margin squeeze regulation, whereas consumers may be worse off due to more severe double marginalization. Second, Ergas et al. (2010) suggest that retail goods are not likely to be homogeneous and Petulowa and Saavedra (2014) show that with horizontally and vertically differentiated products the single integrated firm will only engage in a margin squeeze if its non-integrated competitor is more efficient. In this setting it is found that a margin squeeze ban induces an increase in the integrated firm's retail price, but nevertheless ultimately benefits consumers, because the retail price of the non-integrated firm decreases provided that upstream market regulation is non-constraining. Third, in a market setting that resembles a fixed voice telephony market, Briglauer et al. (2011) demonstrate that increasing infrastructure competition from non-strategic rivals may elicit a margin squeeze depending on access price regulation.

In this chapter, the impact of horizontally differentiated retail goods under infrastructure competition with strategic competitors is scrutinized and it is shown that due to increased competitive pressure in the retail market, margin squeezes occur also in the case when competitors are equally efficient.

Bouckaert and Verboven (2004) identify three types of margin squeezes according to the prevailing regulatory regime: regulatory price squeezes (i.e., if wholesale and retail prices are regulated), predatory price squeezes (i.e., if only wholesale prices are regulated), and foreclosure (i.e., if no prices are regulated). Here, the focus is on the latter type because in industries of competing vertically integrated firms margin squeeze regulation is considered a potential substitute to access price regulation, and not a complement to it. This is exemplified by the *ex ante economic replicability test* from the European Commission's (2013a) recommendation on consistent non-discrimination (see Chapter 2 and Jaunaux and Lebourges, 2015, for a discussion of the recommendation and the ex ante test, respectively).

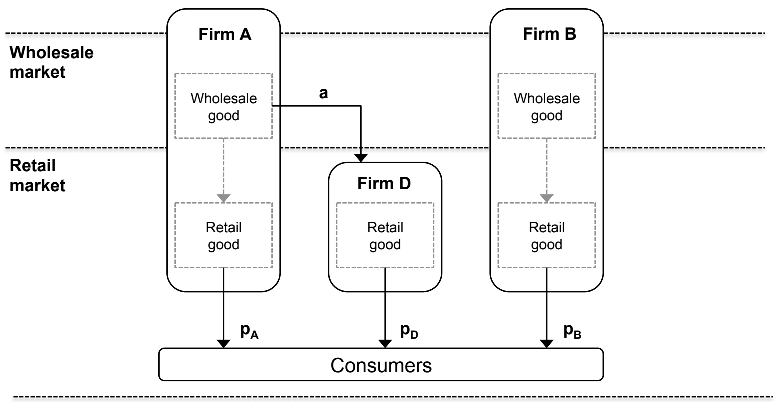
Höffler and Schmidt (2008) also consider strategic interaction between infrastructure operators and retailers and show that, with differentiated retail goods, consumer surplus decreases under *retail minus X* regulation, which is akin to a margin squeeze ban. While their market structure is comparable to the setting in this chapter, Höffler and Schmidt do not consider the emergence of foreclosure, which in fact constitutes an equilibrium outcome as noted by Atiyas et al. (2015). However, as highlighted by Bouckaert and Verboven (2004) and Gaudin and Mantzari (2016), foreclosure is a central concern with regard to margin squeeze conduct. Therefore, the following analysis will distinguish between this more severe *exclusionary* behavior from simple *exploitative* margin squeeze conduct (Jullien et al., 2014). The findings show that margin squeeze regulation prevents both foreclosure and margin squeezes, which benefits a non-integrated competitor, but does not translate into a benefit for consumers. Whereas the effect on the access provider's profit depends on product differentiation and price setting in the retail market, margin squeeze regulation unambiguously increases profit of the integrated firm, which does not supply the wholesale input. On the contrary, it is found that margin squeeze regulation is always detrimental to consumers in the presence of infrastructure competition.

The remainder of this chapter is organized as follows. Next, the general market structure and model that is used to analyze the effect of MSR in lieu of no regulation (NR) is described. In Sections 4.2 and 4.3 two different timing variants of the model are studied. Section 4.4 discusses the policy implications and limitations of the presented model.

## 4.1 Theoretical framework

Consider the industry depicted in Figure 4.1 with two vertically integrated firms (Firm A & Firm B) and a non-integrated firm (Firm D) which operates only in the downstream market. For each unit of its retail good Firm D is required to purchase a unit of the homogeneous upstream good, which Firm A offers at price $a$. Firm B does not provide wholesale access. The retail price of firm $k \in \{A, B, D\}$ is denoted by $p_k$.

FIGURE 4.1: *Market structure (based on Bourreau et al., 2011, p. 683).*




Assuming the representative consumer suggested by Shubik and Levitan (1980) retail goods are horizontally differentiated and demand for firm $k$'s retail good is given by $q_k = \frac{1}{3}(1 - p_k - \gamma(p_k - \frac{p_A+p_B+p_D}{3})$ provided that none of the firms exits the downstream market (Höffler, 2008). Thereby, $\gamma \geq 0$ denotes the degree of substitutability so that high values indicate less differentiated retail goods. In contrast to the case of homogeneous retail goods, competition in differentiated goods requires to distinguish between a *margin squeeze* and *foreclosure* of the downstream firm. More specifically, even if Firm A engages in a margin squeeze, i.e., $\Delta := p_A - a < 0$, Firm D may still make a positive profit, because consumers value variety. If, however, the spread between Firm A's wholesale and retail price exceeds a certain threshold that depends on the degree of substitutability, i.e., $\Delta < \underline{\Delta}(\gamma)$, Firm D cannot make positive profits and therefore exits the market, i.e., it is effectively foreclosed.

In this vein, margin squeeze regulation serves two objectives: (i) to establish a level playing field by prescribing that no firm sets its retail price below the market wholesale price and (ii) to safeguard product variety by ensuring that non-integrated firms are not foreclosed from the market. Whether it is profitable for the access provider, Firm A, to foreclose the downstream retailer, Firm D, with respect to the model depends on the degree of substitutability, $\gamma$, and the strategic role of Firm D. In Section 4.2 Firm D is considered to act as a competitive fringe, which sets its retail price after observing the retail prices of the integrated firms. In the absence of MSR, i.e., under NR, Firm D will be subjected to a margin squeeze in this scenario, but will never be foreclosed. In Section 4.3 an alternative timing of the model is considered, where Firm D sets its retail price simultaneously with the integrated firms. In this scenario, both margin squeeze and foreclosure may occur under NR.

## 4.2 Competitive retail fringe

When Firm D is thought of as a competitive fringe that reacts to the integrated firms' prices, the timing of the model is as follows:

*Stage 1*: Firm A sets the wholesale price $a$.

*Stage 2*: Firm A and Firm B set their respective retail prices $p_A$ and $p_B$.

*Stage 3*: Firm D sets its retail price $p_D$.

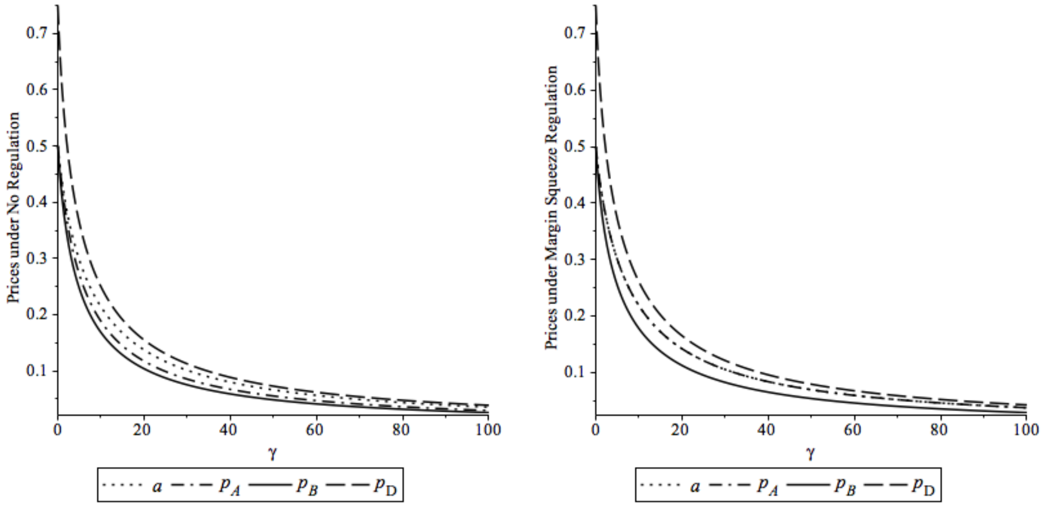
The subgame-perfect equilibrium of this game is determined by backward induction for the case of NR, where Firm A can set its prices freely, and for the case of MSR, where Firm A must adhere to the constraint $\Delta \geq 0$. For a welfare analysis of MSR in lieu of NR not only firms' prices $p_k$, quantities $q_k$, and profits $\pi_k$ are compared, but also producer surplus $PS = \sum_k \pi_k$, i.e., the sum of firms' profits, consumer surplus $CS = \sum_k q_k - \frac{3}{2(1+\gamma)}(\sum_k q_k^2 + \frac{\gamma}{3}(\sum_k q_k)^2) - \sum_k q_k p_k$, i.e., the representative consumer's net utility (Bouckaert and Kort, 2014), and total surplus $TS = PS + CS$. In order to assess MSR relative to NR, ratios $\phi X_k = \frac{X_k^{MSR}}{X_k^{NR}}$ are reported, where $X$ is the market variable under investigation. In the following, a sketch of the analysis and some intuition for the results are offered, whereas the technical details are relegated to Appendix A.2.

**RESULT 4.1.** *If the access provider has no incentive to foreclose its downstream rival under no regulation, margin squeeze regulation increases wholesale and retail prices, which leads to a loss in consumer surplus and total surplus.*

Under NR, in Stage 3 Firm D's first order condition is $\frac{\partial \pi_D}{\partial p_D} = 0$, which yields $p_D^{NR} = \frac{1}{2}\frac{2a\gamma+\gamma p_A+\gamma p_B+3a+3}{3+2\gamma}$ as the best response to the integrated firms' prices. In stage 2, both integrated firms $i \in \{A, B\}$ solve $\frac{\partial \pi_i(p_D^{NR})}{\partial p_i} = 0$ simultaneously, yielding $p_A^{NR}$ and $p_B^{NR}$, respectively. Anticipating these decisions, Firm A solves $\frac{\partial \pi_A(p_A^{NR}, p_B^{NR}, p_D^{NR})}{\partial a} = 0$ in Stage 1 and sets the optimal wholesale charge $a^{NR}$ accordingly. The left panel of Figure 4.2 depicts the equilibrium retail and wholesale prices. Notice that Firm A violates the margin squeeze condition for all $\gamma > 0$. Yet, Firm D makes positive profits in equilibrium as Firm A has no incentive to foreclose the retailer. In other words, Firm A benefits more from the *wholesale revenue effect* than it suffers from the *business stealing effect*. In contrast, Firm B prefers foreclosure of Firm D, because it suffers from the business stealing effect and has no wholesale revenue to compensate for this. Relatedly, Firm B sets lower retail prices than Firm A due to the *softening effect* (Bourreau et al., 2011; Fudenberg and Tirole, 1984), which occurs because Firm B has no opportunity cost in terms of foregone wholesale revenue when decreasing its retail price.

Under MSR, however, Firm A's retail price setting in Stage 2 is constrained, because a margin squeeze would occur for all $\gamma > 0$ under NR. This induces Firm A to raise its retail price to the level of the profit maximizing wholesale price, i.e., $p_A^{MSR} = a^{MSR}$. Otherwise, wholesale revenue, business stealing, and softening effects are qualitatively

FIGURE 4.2: *Equilibrium prices under NR and MSR.*

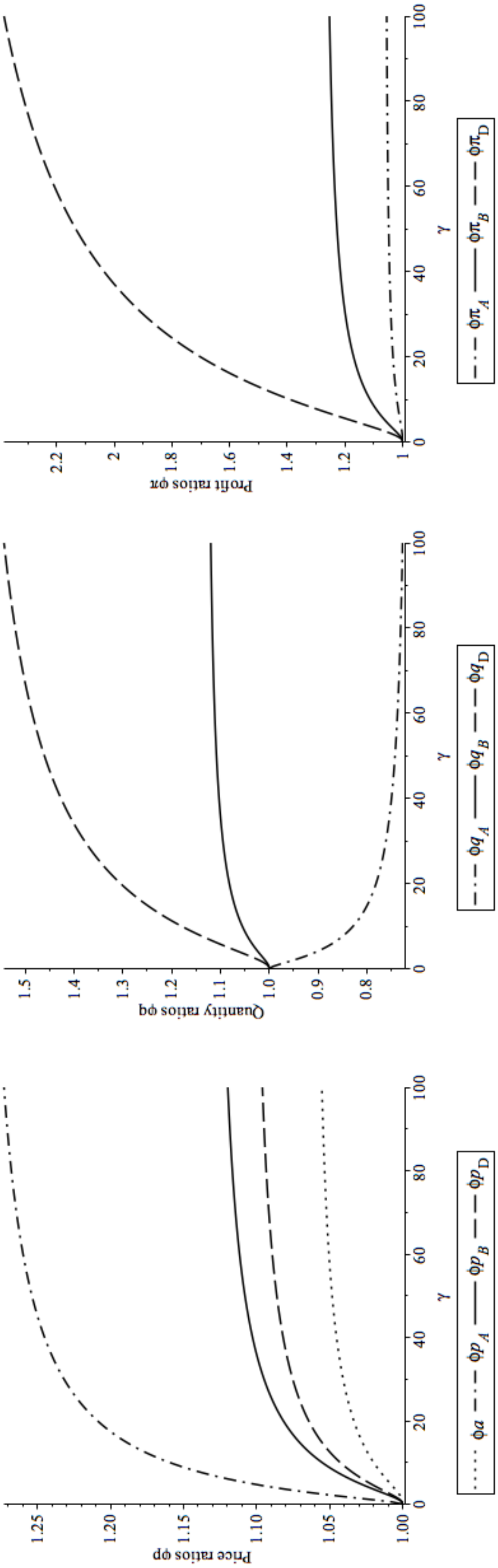



the same as under NR which preserves the relative order of equilibrium prices (see the right panel of Figure 4.2).

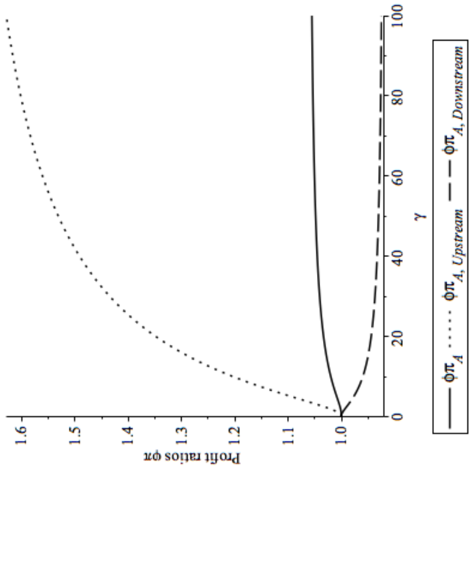
Figure 4.3a depicts the net effect of MSR in comparison to NR with respect to its relative impact on prices, quantities, and profits. First, the reported ratios demonstrate that all prices rise under MSR, which highlights that the regulation not only fails to exert a negative impact on the wholesale price, but instead allows firms to attain higher prices in both wholesale and retail markets. Since the margin squeeze condition is binding, Firm A has no incentive to lower its retail price following an increase in its wholesale price. This in turn incentivizes Firm B to increase its retail price as well, because downstream prices of the integrated firms are strategic complements. In addition, Firm D raises its retail price due to the increased wholesale input price. Second, despite this universal price increase, retail demands for Firm B and Firm D increase, and only Firm A's demand decreases due to the relative magnitude of its price surge compared to NR. Third, profits increase for all firms under MSR. Whereas Firm A's downstream profit deteriorates due to a decline in retail demand, the increase in wholesale revenue ultimately leads to a net benefit for the access provider as shown in Figure 4.3b.

The welfare analysis of MSR in relation to NR reinforces insights on the effect of MSR gained thus far (see Figure 4.3c). While producer surplus increases under MSR as a

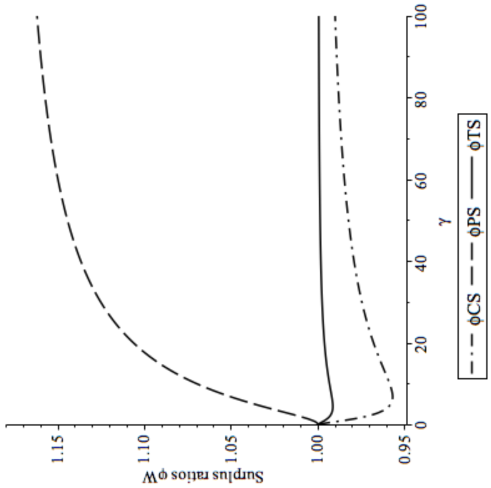
FIGURE 4.3: *MSR effect on market variables in the scenario with a competitive retail fringe.*




(A) *Firms' prices, quantities, and profits.*




(B) *Firm A's total, upstream, and downstream profit.*




(C) *Consumer surplus, producer surplus, and total surplus.*

direct consequence of firms' ability to unanimously reap higher profits, consumer surplus is lower than under NR. More specifically, consumers are worse off because the increased outputs of Firm B and Firm D are outweighed by higher retail prices of all firms. Remarkably, note that the harm to consumers due to MSR decreases with increasing substitutability of retail goods. Overall, the effects on producer and consumer surplus amount to an ultimately negative impact of MSR on total surplus, which is more severe for more differentiated retail goods, i.e., for lower values of $\gamma$. Altogether these results suggest that under the given market structure and timing, MSR cannot be justified by either a consumer welfare perspective nor a total welfare standard.

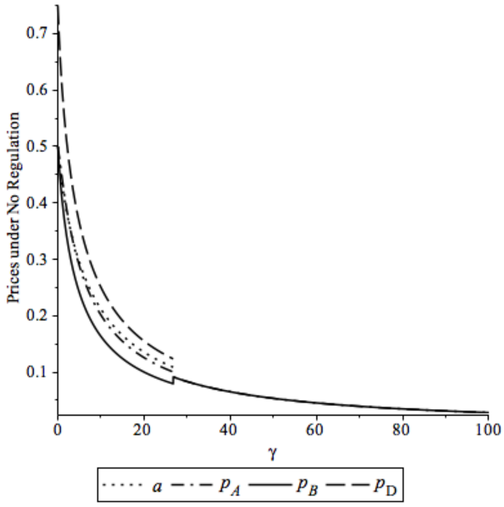
## 4.3 Simultaneous retail pricing

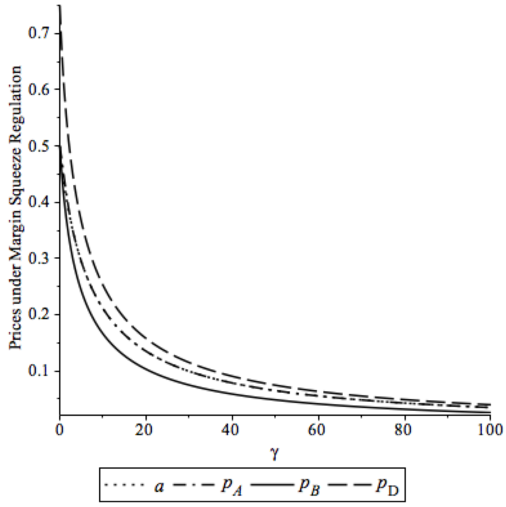
The scenario studied in the previous section may be contested based on the claim that MSR is particularly relevant and potentially more effective in a scenario where the access provider does not only engage in a margin squeeze but is also likely to effectively foreclose the non-integrated retailer from the downstream market. Thus, a second scenario, where the competitive position of the non-integrated retailer is strengthened, and thus foreclosure constitutes an equilibrium under NR if retail goods are close substitutes is scrutinized in the following. In particular, the case where all (integrated and non-integrated) firms choose their retail prices simultaneously, which reduces the previous three-stage game to a two-stage game is now considered. Again, the focus is on the cornerstones of the analysis, whereas the technical details are provided in Appendix A.2.

**RESULT 4.2.** *If the access provider has an incentive to foreclose its downstream rival under no regulation, margin squeeze regulation prevents the market exit of the non-integrated retailer. Whereas total surplus increases due to higher profits, consumer surplus always decreases.*

Under NR, in Stage 2 all firms choose their retail prices given the wholesale price. In Stage 1, Firm A decides on its wholesale price by trading off its profits when it does or

FIGURE 4.4: *Equilibrium prices under NR and MSR.*



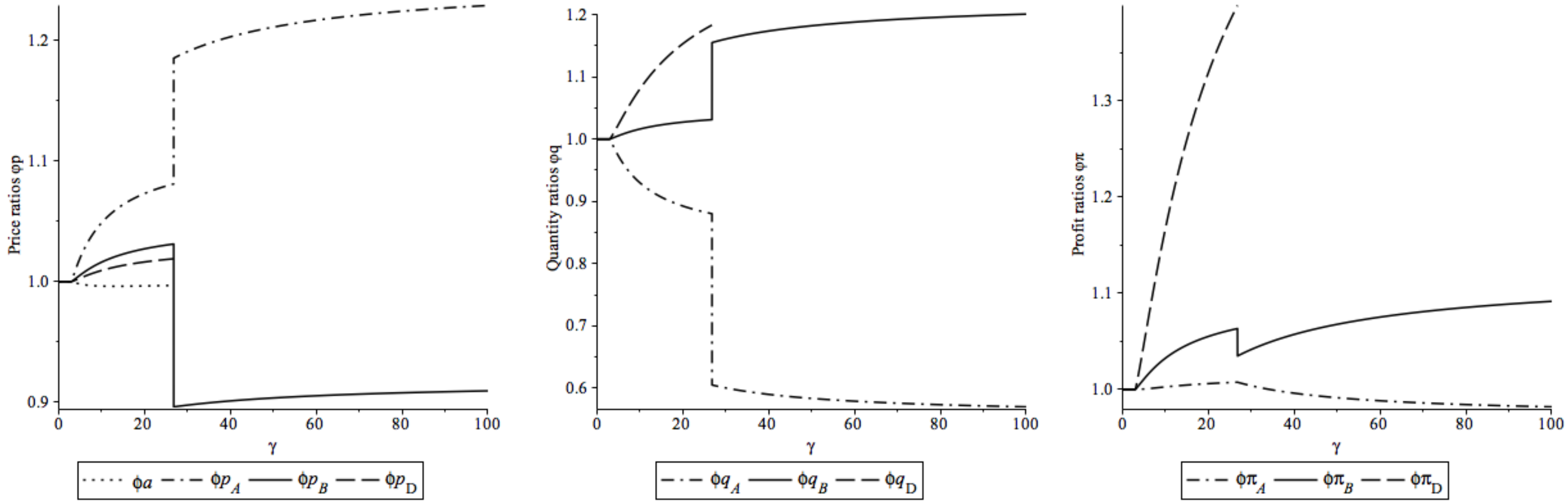




does not provide a viable wholesale offer to Firm D. Atiyas et al. (2015) and Bourreau et al. (2011) show that Firm A prefers foreclosure of Firm D if $\gamma > \overline{\gamma} := 26.77$. In this case Firm A sets a foreclosure wholesale price of $a^{NR} > \frac{5\gamma+6}{\gamma^2+7\gamma+6}$. The left panel of Figure 4.4 depicts ensuing equilibrium retail prices. Note that, due to the foreclosure of Firm D, the softening effect disappears for $\gamma > \overline{\gamma}$ and both integrated firms charge identical retail prices. Furthermore, Firm A engages in a margin squeeze for all $\gamma > 3$.

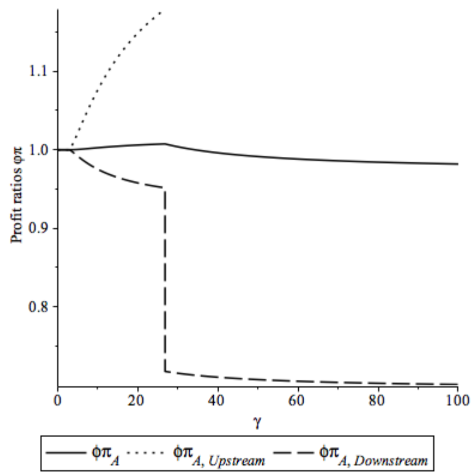
Consequently, under MSR the margin squeeze condition is binding iff $\gamma > 3$. Thus, MSR effectively prevents foreclosure of Firm D, because Firm A is now required to make a viable wholesale offer. The resulting equilibrium prices are shown in the right panel of Figure 4.4.

Figure 4.5a depicts the net effect of MSR on prices, quantities, and profits. If retail goods are sufficiently differentiated so that foreclosure is not an equilibrium, i.e., $\gamma \leq \overline{\gamma}$, the net effects are similar to those observed in the previous scenario. The only exception is that, in this scenario, MSR induces the access provider to reduce its wholesale price relative to NR. However, similar to the previous scenario, Firm D increases its retail price due to the stronger strategic complements effect in the retail market. If, instead, retail goods are less differentiated, i.e., $\gamma > \overline{\gamma}$, Firm A's retail price increases and Firm B's retail price decreases under MSR relative to NR. The opposite holds for the integrated firm's

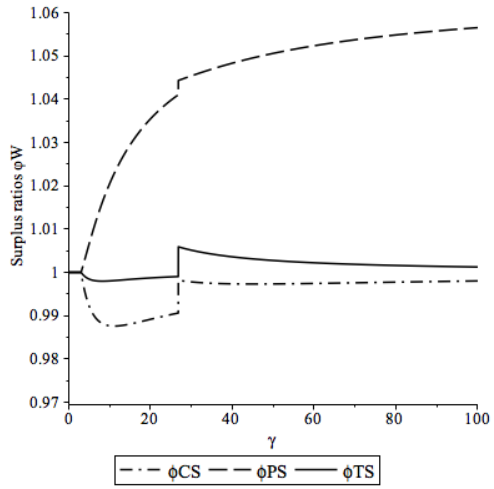
FIGURE 4.5: *MSR effect on market variables in the scenario with simultaneous retail pricing.*




(A) *Firms' prices, quantities, and profits.*




(B) *Firm A's total, upstream, and downstream profits.*




(C) *Consumer surplus, producer surplus, and total surplus.*

retail demand. Since MSR prevents Firm D's foreclosure, its price, demand, and profit are strictly positive. With respect to Firm A's profit, the net effect of MSR is ambiguous. Whereas for $\gamma \in (3, 34.20)$ increasing wholesale revenue outweighs losses in retail profit so that Firm A benefits from the regulation, the opposite holds if retail goods are very close substitutes, i.e., $\gamma > 34.20$ (see Figure 4.5b).

The welfare analysis of MSR for this scenario is depicted in Figure 4.5c and indicates similar effects as in the first scenario for $\gamma \leq \overline{\gamma}$. With less differentiated retail goods, i.e., $\gamma > \overline{\gamma}$, consumers are better off than with rather differentiated goods due to the foreclosure ban owed to MSR, however, they are still worse off than under NR. In contrast, producers are better off under MSR due to increased profits of Firm B and Firm D. Remarkably, the increase in producer surplus compensates the loss in consumer surplus, yielding an increase in total surplus for $\gamma > \overline{\gamma}$. Thus, MSR is beneficial from a total welfare perspective in case of foreclosure—however, this effect emerges from increased producer surplus, and not from increased consumer surplus.

## 4.4 Discussion

This chapter scrutinizes margin squeeze regulation in the presence of infrastructure competition and monopolistic wholesale access based on an analytic game-theoretic model. More specifically, a setting with two integrated firms of which one offers its wholesale good whereas the other does not, and one non-integrated firm that depends on the wholesale good as an input to produce its retail good is considered. In contrast to a market with a single integrated firm, it is shown that under infrastructure competition the access provider may engage in a margin squeeze also in the case of an equally efficient retailer. The central finding is that margin squeeze regulation is detrimental to consumers, irrespective of the substitutability of retail goods and the timing of firms' decisions. This result is supported and extended by several insights.

First, if the access provider has no incentive to foreclose its downstream rival, margin squeeze regulation unanimously increases wholesale and retail prices, which leads to a loss in consumer surplus and ultimately even total surplus. Second, if foreclosure is an equilibrium, margin squeeze regulation prevents the market exit of the non-integrated retailer. Although this may lead to a decrease in the wholesale price and an increase in total surplus, this does not translate into consumers' benefit, but only into higher firms' profits. Third, margin squeeze regulation benefits all firms individually. The only exception is that the access provider may be worse off under the regulation if and only if it wants to foreclose the downstream firm and if the retail goods are close substitutes. In this case, the access provider makes less profit than its integrated rival, which is likely to evoke non-price discrimination (cf. Mandy and Sappington, 2007).

These findings bear important policy implications. Note that antitrust investigations of margin squeezes and corresponding regulation are largely enacted in markets where multiple integrated firms produce an upstream input good, i.e., in industries with infrastructure competition next to service-based downstream competition. In fact, the European Commission (2013a) argues that infrastructure competition is a necessary condition for margin squeeze regulation to replace traditional access price regulation. This rationale is based on the conjecture that retail prices are already constrained by competition under these circumstances and thus the access provider is compelled to lower its wholesale price to comply with the requirements of the regulation. The presented findings indicate that this reasoning is flawed if firms compete in prices that are strategic complements, which is likely to apply to network industries such as telecommunications, but also to other industry contexts. In this case, competitors raise their retail prices in anticipation of the access provider's constrained pricing ability. Furthermore, a positive total welfare effect of margin squeeze regulation only occurs if the non-integrated retailer is foreclosed under no regulation. However, even then the integrated firm which does not provide access has a competitive advantage over the access provider. Thus, margin squeeze regulation reduces the incentives to provide access which is contrary to its original rationale as an Open Access rule. Moreover, European authorities currently do not distinguish between (non-)foreclosure scenarios in margin squeeze investigations. Even if they did, the presented results raise skepticism with regard to the alleged goal of margin squeeze regulation, i.e., to establish a level playing field for competition, as well as to the ultimate objective of regulatory intervention, i.e., to protect consumers.

The analyses conducted in this chapter are limited to price competition in the retail market. With competition in quantities decisions constitute strategic substitutes, which may affect the mechanics of margin squeeze regulation. Yet, in Appendix A.2, a model with differentiated quantity competition à la Singh and Vives (1984) is considered, which yields similar welfare implications with respect to margin squeeze regulation.

Furthermore, the investigations here abstract from cost asymmetries between integrated firms and non-integrated retailers as well as different application contexts of margin squeeze regulation in ex post antitrust on the one hand and ex ante sector-specific regulation on the other hand. This latter issue has been discussed thoroughly from a competition law perspective (Geradin and O'Donoghue, 2005; Heimler, 2010). Whereas authorities' objective—and therefore their assessment of market outcomes—may differ in these application contexts, the presented economic effects arise irrespective of an ex post or ex ante application of the margin squeeze rule. With regard to cost asymmetries, Gaudin and Saavedra (2014) summarize the debate on whether a margin squeeze test should be based on an *Equally Efficient Operator* or a *Reasonably Efficient Operator* standard. As the results in this chapter apply to the stricter standard of an equally efficient retailer, the consideration of a less efficient retailer would further worsen market outcomes from the view of consumers in light of yet higher retail prices. Taking into account additional complexity (e.g., due to non-linear pricing or bundling), which in practice is likely to increase the number of false-positive findings of margin squeeze conduct (Ergas et al., 2010), augments the issues that already arise in the simplified setting of this study.

With respect to future work, the ineffectiveness of margin squeeze regulation to increase consumer surplus calls for alternative regulatory approaches in cases when there is infrastructure-based *and* service-based competition at the same time. It has been observed that it is not desirable to rely on (symmetric) access price regulation in this case (cf. Bacache et al., 2014), because the inherent trade-off between static and dynamic efficiency is likely to stifle investments in infrastructure (see the survey with respect to OA in Chapter 2). Instead, wholesale competition between the integrated firms may be seen as a potential alternative to safeguard low input prices for non-integrated competitors and to establish a level playing field in the retail market, although theoretical research points to cases where competition at the upstream level may fail to improve market outcomes relative to the monopoly case (Bourreau et al., 2011). Thus, further research devoted to the design and empirical evaluation of new regulatory institutions in an environment of competing infrastructures seem to be highly relevant from an academic and policy perspective. Therefore, the next chapter is dedicated to an experimental analysis of Open Access mechanisms, which encompasses both the test of an established regulatory institution, in particular margin squeeze regulation, under different market conditions as well as the evaluation of a more *behaviorally oriented* and new regulatory instrument, in particular price commitment.

# Chapter 5

# Wholesale Competition and Open Access Regulation

REGULATION of wholesale access to an upstream bottleneck resource that represents an essential input for non-integrated firms to compete in the retail market downstream stimulates considerable economic research. The anti-competitive effects that possibly arise in such a scenario as well as accompanying regulatory remedies (Armstrong et al., 1996; Armstrong and Vickers, 1998) are widely studied in the literature for the case of a single access provider. Moreover, firms' strategic incentives to vertically integrate across retail and wholesale markets and the effect of such conduct on competition (see Lafontaine and Slade, 2007, for an overview) have been thoroughly investigated, in particular with respect to the softening of retail competition (Chen, 2001; Gans, 2007) and foreclosure of non-integrated retailers (Hart and Tirole, 1990; Ordover et al., 1990; Choi and Yi, 2000; Rey and Tirole, 2007b) or upstream rivals (Chen and Riordan, 2007). Economic laboratory experiments have complemented the theoretical literature, most notably concerning the issue of vertical foreclosure (Martin et al., 2001; Normann, 2011). However, a set of new issues arises when there is more than one vertically integrated access provider such that competition at the wholesale level may emerge in addition to retail competition. Especially in the likely case of a highly con-

This chapter is based on joint work with Niklas Horstmann and Jan Krämer (Horstmann et al., 2016c).

centrated (duopoly) wholesale market the question arises whether access regulation is (still) warranted. Evidently, the answer to this question will have direct ramifications on how regulators and competition authorities should deal with this kind of market structure, but also on whether authorities should promote the entry of a second integrated access provider in markets in which the essential input is currently supplied monopolistically.

This chapter scrutinizes the effect of wholesale competition on market performance in terms of market prices, firms' profits and consumer surplus by explicitly taking into account the emergence of tacit collusion that may arise in this scenario. Based on a framework of two integrated firms and one non-integrated retailer (Bourreau et al., 2011), an economic laboratory experiment is designed that allows to empirically observe market performance under various modes of wholesale competition while keeping all other factors fixed. Moreover, a continuous time framework is employed, which allows firms to change and observe wholesale and retail prices at any time, and thus, endogenizes the timing of the price setting (see Section 3.3).

More specifically, the study considers three different market scenarios: First, the case where only one of the integrated firms provides wholesale access (access monopoly) is examined. This constitutes the benchmark case, which is extensively studied in the literature. Second, standard homogeneous Bertrand competition between the two integrated firms at the wholesale level is considered. In this setting, firms can adjust their wholesale prices at any time and the firm that offers the lower price serves the entire wholesale market. Third, as Bertrand competition is known to be susceptible to tacit collusion (Potters and Suetens, 2013), a variant of Bertrand competition at the wholesale level is additionally considered in which integrated firms are obliged to maintain their wholesale price for a fixed period of time (i.e., a price commitment), everything else being equal to the second case. Due to this price commitment, the firm that decides on the lower price is granted a wholesale monopoly position for some time. Thus, this latter treatment induces an element of *competition for the market* (Geroski, 2003), which is conjectured to hinder tacit collusion and to intensify competition at the wholesale level.

All three modes of wholesale competition are examined both under a no regulation regime, where firms are free to set wholesale and retail prices, and under a margin squeeze regulation regime, in which an integrated firm's wholesale price may not exceed its retail price. As described in the previous chapter, margin squeeze regulation has recently gained attention in the debate on Open Access policies and is perceived as a viable alternative to price regulation, e.g., by the European Commission (2013a), particularly when there is more than one wholesale access provider.

The analyzed issues arise most prominently in network industries such as the telecommunications (see Chapter 2) and energy (Boots et al., 2004) industries, in which the bottleneck arises naturally through subadditivity of the cost structure. Yet, access to an upstream resource is also of concern in other contexts such as the licensing of intellectual property (Dewatripont and Legros, 2013), where the bottleneck is constituted artificially. Although not confined to this context, the relevance of the considered market scenario of competing access providers can be exemplified by the telecommunications industry. Due to technological progress and consolidation both the fixed and the mobile industries are characterized by few vertically integrated firms, as well as several non-integrated retailers that rely on access to an upstream resource. On the one hand, with respect to fixed networks, technological progress led to the roll out of new fiber-optic networks as well as the evolution of broadband cable networks, which both created new vertically integrated firms that compete most notably in densely populated urban areas with the traditional telecommunications incumbent. On the other hand, mobile telecommunications markets recently experienced a wave of mergers and acquisitions that reduced the number of independent operators maintaining a distinct cellular infrastructure, thus increasing market concentration at the wholesale level.

Despite its practical relevance, the explicit analysis of simultaneous wholesale *and* retail competition in the presence of *both* vertically integrated and non-integrated firms received little attention in the literature. The extant theoretical analyses, which are reviewed in detail below, suggest that wholesale competition is likely to improve and not deteriorate market performance compared to the case of a wholesale monopoly, although monopoly-like equilibria may exist. Thereby, the theoretical models generally rest on the assumption of effective competition at the wholesale level, in particular by assuming homogeneous Bertrand competition between duopolistic access providers (see, e.g., Bourreau et al., 2011). However, empirical results from both laboratory (Engel, 2007; Potters and Suetens, 2013) and field studies (see, e.g., Parker and Röller, 1997, in the context of telecommunications markets) suggest that duopoly markets are prone to high levels of *tacit collusion*, which may give rise to market outcomes that differ from those identified in the theoretical literature (see also Chapter 6).

The results of this study indicate that, over and beyond the findings of the theoretical literature, wholesale competition may in fact lead to a worse market outcome for consumers than a wholesale monopoly. For the case of standard Bertrand competition at the wholesale level both wholesale as well as retail market prices are above the level that is observed when there is only a single access provider. Drawing on the literature on upstream collusion (Nocke and White, 2007; Normann, 2009) it is shown that incentives for tacit collusion are actually higher under wholesale competition if an infinitely repeated game context is considered. Thus, even in the presence of wholesale competition regulators should closely monitor the performance of such vertically related markets. However, the results also demonstrate that wholesale competition may be intensified by a simple price commitment rule, which in turn restores the theoretical prediction to the extent that access prices are lower than under a wholesale monopoly. Nevertheless, even in this case, wholesale access prices remain well above the predicted Nash equilibrium. Furthermore, in the context of the Open Access debate, there is no evidence that a margin squeeze regulation reduces retail market prices compared to a no regulation regime, which is in line with the findings for a wholesale monopoly in Chapter 4. Although margin squeeze regulation may benefit the retailer, it tends to increase retail prices and thus reduce consumers' surplus.

The remainder of this article is structured as follows. Section 5.1 surveys the related literature on wholesale competition as well as recent studies which have dealt with the margin squeeze rule. In Section 5.2, the experimental design is described and hypotheses are derived from the theoretical predictions for four timing variants of the basic model. Section 5.3 presents the experimental results. In Section 5.4, results are examined with respect to the hypotheses and incentives for tacit collusion in a repeated game context are discussed. Finally, Section 5.5 identifies limitations and points out possible extensions.

## 5.1 Related literature

### 5.1.1 Wholesale monopoly and competition

Before reviewing the literature on wholesale competition, it is worth noting some of the effects that arise already in the presence of a monopolistic access provider. Even in the absence of regulation a vertically integrated firm may be willing to supply the wholesale market on a voluntary basis if the additional revenues generated at the upstream level exceed the business stealing effect of the retailer in the downstream market (Farrell and Weiser, 2003; Höffler and Schmidt, 2008). More generally, if downstream organizations exhibit efficiency advantages or if retail goods are sufficiently quality-differentiated (e.g., due to brand reputation or additional sales channels as illustrated by Banerjee and Dippon, 2009), the provision of wholesale services will allow the integrated firm to generate additional revenues. In this case, the access provider benefits from a demand expansion effect relative to a situation where the integrated firm is the single seller of its goods in the retail market (Boudreau, 2010).

In the presence of wholesale competition the incentives to provide access on a voluntary basis are likely to be increased compared to a wholesale monopoly, because the integrated firms may now find themselves in a prisoner's dilemma with respect to the provision of the wholesale good (Brito and Pereira, 2010). Studies that investigate these incentives have examined the conditions under which retailers are supplied in equilibrium and whether resale actually improves downstream market performance, particularly in terms of market prices. The majority of these studies considers price competition with horizontally differentiated retail products (Ordover and Shaffer, 2007; Brito and Pereira, 2010; Höffler and Schmidt, 2008; Bourreau et al., 2011; Atiyas et al., 2015) where competition is either spatial (Hotelling, 1929; Salop, 1979) or non-spatial (Shubik and Levitan, 1980). The remainder assumes quantity competition in the retail market (Dewenter and Haucap, 2006; Kalmus and Wiethaus, 2010). Although the precise nature of the supply and non-supply equilibria as well as the retail equilibria that emerge under wholesale competition depend on the specific modeling assumptions, all theoretical investigations agree that wholesale competition neither leads to more foreclosure of the retailer nor increases wholesale or retail market prices in comparison to a wholesale monopoly.

More specifically, under wholesale competition Ordover and Shaffer (2007) as well as Brito and Pereira (2010) find that integrated firms provide the retailer with the retail good at marginal cost if products are sufficiently differentiated, although they would be individually better off without entry as retail prices and profits decrease. On the contrary, retailers are generally not supplied if retail products are close substitutes and none of the integrated firms has an incentive to make a profitable wholesale offer in the first place. Furthermore, Ordover and Shaffer show that the supply equilibrium disappears if input goods are differentiated, or if the retailer chooses its quality endogenously and cannot commit ex ante to its product positioning.

Moreover, the analyses by Brito and Pereira (2010) and Höffler and Schmidt (2008) reveal that if competition is spatial and the degree of quality differentiation is intermediate, one integrated firm may provide access while the other integrated firm makes an unprofitable offer. This finding of a *partial foreclosure equilibrium* is further generalized—including the case of non-spatial competition—by Bourreau et al. (2011) based on the characterization of the *softening effect*: A vertically integrated wholesale provider chooses its retail price with regard to its opportunity costs in the wholesale market (DeGraba, 2003) and thus will be less aggressive in the retail market than its vertically integrated rival who does not provide wholesale access. In other words, the consideration of opportunity costs weakens competition in the retail market and may at the same time make it less attractive to compete for wholesale revenues. In consequence, the monopoly outcome may be restored, because the integrated rival of the access provider benefits from higher retail profits and thus prefers to exit the upstream market. Note, however, that the equilibrium hinges on the assumptions that retail goods are close substitutes *and* that at least one firm supplies the retail firm, e.g., due to a retailer's efficiency advantage (Bourreau et al., 2011) or due to regulatory coercion (Bourreau et al., 2015). Otherwise, marginal cost pricing in the upstream market constitutes the unique equilibrium under wholesale competition in the non-spatial model if goods are sufficiently differentiated (Höffler and Schmidt, 2008). Moreover, Atiyas et al. (2015) show that unobservable, more complex wholesale contracts may stimulate voluntary access and wholesale competition, thus making foreclosure of the retailer less likely.

Höffler and Schmidt (2008) investigate the effects of resale on consumer welfare, which may be increased either by a decline in retail prices and/or an increase in variety. Under the assumption that the retailer will be supplied by one of the integrated firms, i.e., there is no foreclosure, it is shown that resale may actually increase the market price if quality differentiation is sufficiently high. In the case of non-spatial competition the price increase is always compensated by an increase in variety with respect to consumer welfare. In the spatial model however, consumers may be worse off as the price effect dominates. Then again, if wholesale competition for retailers is considered in the non-spatial model, wholesale prices are found to equal marginal cost and, in consequence, retail prices are lower than compared to a situation without resale.

Whereas the reported analyses of wholesale competition focus exclusively on the one-shot interaction between firms, the literature on upstream collusion examines incentives for coordinated firm behavior in an infinitely repeated game setting. Nocke and White (2007) compare critical discount factors that are necessary to sustain collusion by the means of grim trigger strategies and find that vertical integration facilitates tacit collusion among upstream firms relative to a vertically separated industry structure. Normann (2009) replicates the finding that vertical integration facilitates upstream collusion for the case of linear input charges and a *sequential* setting of wholesale and retail prices, whereas Nocke and White model wholesale contracts as two-part tariffs and assume *simultaneous* price setting.

This study contributes to the literature on wholesale competition by showing empirically that wholesale prices may be above the monopoly level even if theory predicts wholesale supply at marginal costs as the unique equilibrium. It is further shown that tacit collusion at the wholesale level may effectively be reduced by a price commitment rule that fosters the integrated firms' competition for the market. Moreover, the experimental framework allows for a systematic comparison of retail market performance in terms of wholesale and retail prices, firms' profits and consumer surplus under the different modes of wholesale competition. Finally, the experimental design in continuous time endogenizes the timing of firms' price setting, and thus reconciles different timings proposed in the theoretical literature.

### 5.1.2 Margin squeeze regulation

In the presence of a duplicate infrastructure the traditional economic rationale for ex ante price regulation is no longer applicable as the bottleneck does not represent a single essential facility anymore (Renda, 2010). In consequence, regulators and competition agencies may be concerned with identifying suitable alternatives and regulatory rules that still ensure *Open Access* for downstream competitors, but give integrated firms more freedom in setting their wholesale prices (see Chapter 2). As described in Chapter 4, the margin squeeze rule represents a potential surrogate for price regulation that is already applied in various forms and different contexts. Next to its application in (European) competition law, the basic mechanism, which is designed to ensure a viable wholesale-retail margin for a downstream retailer, is also implemented by *re-*

*tail minus X regulation* (Gonçalves, 2007) and the *efficient component-pricing rule* (Baumol et al., 1997). Ever since the landmark decision *Deutsche Telekom*[1] in 2003, the application of the margin squeeze rule as an antitrust instrument is controversially debated within the economic and the legal literature (Briglauer et al., 2011; Carlton, 2008; Geradin and O'Donoghue, 2005). While the European Commission has repeatedly convicted firms based on a margin squeeze accusation[2] and has been confirmed by European courts[3], the US Supreme Court has dismissed allegations based on the margin squeeze rationale in comparable cases (*Trinko* and *linkLine*).

The rationale for margin squeeze regulation is that protecting competitors in the context of monopolistic bottlenecks or concentrated input markets will ultimately benefit consumers. Particularly in competition policy the latter goal is emphasized and held in high regard, e.g., the European Commission (2009a, p.7) clarifies that "what really matters is protecting an effective competitive process and not simply protecting competitors". Sector-specific regulation may widen the scope of application, as is illustrated by the debate about the relevant efficiency standard for the margin squeeze conduct (Geradin and O'Donoghue, 2005), but fundamentally still aims at the protection of consumers, where competition itself is a means to an end (Vogelsang, 2013).

In this vein, Jullien et al. (2014) provide an overview of the economic theories of harm that may qualify a margin squeeze as an abuse of market power and could provide the basis for a stand-alone antitrust doctrine. Petulowa and Saavedra (2014) qualify the circumstances under which a margin squeeze can occur in the case of differentiated goods and state that a margin squeeze is rather the result of competition and not of an exploitative abuse. Jullien et al. conclude that the effects of a margin squeeze rule are ambiguous as wholesale prices may decrease, but retail prices may also rise, due to a *price umbrella effect*. With regard to retail minus X regulation, Höffler and Schmidt (2008) criticize that its application may lead to consumer welfare losses and higher prices.

[1] Commission Decision 2003/707/EC.

[2] See the Commission Decision of 4 July 2007 (Case COMP/38.784 – *Wanadoo España vs. Telefónica*).

[3] See the cases *Deutsche Telekom* (T-271/03, C-280/08), *Telefónica* (T-336/07, T-398/07 C-295/12) and *Telia-Sonera* (C-52/09).

In the past, the margin squeeze rule has mostly been investigated in the case of a single access provider, as indispensability has initially constituted a central criterion in its application as an antitrust instrument. More recently, as illustrated by the *ex ante economic replicability test* in the European Commission's 2013a recommendation on consistent non-discrimination, the margin squeeze test may also be applied to an environment with competing infrastructures (Jaunaux and Lebourges, 2015). Although this rule is already applied in practice, little research has been conducted with regard to actual consequences in the particular application context of infrastructure and wholesale competition. This study complements the theoretical analysis of margin squeeze regulation in the context of infrastructure competition with an experimental evaluation and further extends the examination to the context of wholesale competition.

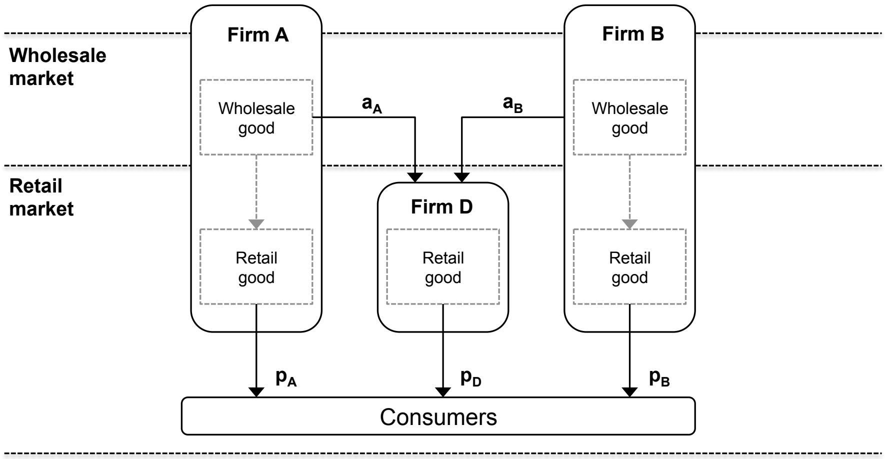
The experimental evidence obtained in this study suggests that the margin squeeze rule is likely to be ineffective in lowering retail prices irrespective of the mode of wholesale competition. Although margin squeeze regulation may benefit the retailer in some circumstances, it tends to increase retail prices and thus reduces consumer surplus.

## 5.2 Experimental framework

### 5.2.1 Theoretical model

The underlying experimental framework explicitly addresses the presented issues of wholesale competition and Open Access by incorporating a market design that allows for competition at the wholesale and retail level. The general experimental design is based on the model of upstream competition analyzed by Bourreau et al. (2011)—illustrated in Figure 5.1— in which two integrated firms (Firm A & Firm B) are able to supply the wholesale good, while a third firm (Firm D) operates only in the downstream market. In order to supply the retail good, the downstream retailer is required to purchase the wholesale good at the upstream market from one of the two integrated

FIGURE 5.1: *Conceptual model of wholesale competition with two integrated firms and a non-integrated retailer (based on Bourreau et al., 2011, p. 683).*




firms. The wholesale prices of Firm A and Firm B are denoted $a_A$ and $a_B$, respectively. In the retail market, all firms choose their respective retail prices $p_k$, $k \in \{A, B, D\}$.

It is assumed that Firm D chooses the wholesale product with the lowest price and does not split its demand.[4] Thus, the integrated firms compete à la Bertrand with homogeneous goods. For each quantity that the downstream retailer supplies to consumers in the retail market it must buy an identical quantity of the wholesale good. In the downstream market, firms compete likewise in prices, but goods are differentiated. In line with previous theoretical studies on wholesale competition, competition in horizontally differentiated goods based on Shubik and Levitan (1980)[5] is assumed, where the retail demand of each firm $k$ in the case of $n = 3$ active firms is given by $q_k = \frac{1}{3}(1 - p_k - \gamma(p_k - \frac{\sum_{i=1}^{3} p_i}{3}))$ and the differentiation parameter $\gamma$ defines the degree of substitution between firms' retail goods. Across all treatments, $\gamma = 30$, which corresponds to a diversion ratio of $^{10}/_{21}$ for each pair-wise relationship between firms (Shapiro, 1996).

[4]Note that, as the stage game is played repeatedly in the experiment, the following tie breaking rule is used: If Firm A and Firm B offer the same wholesale price, Firm D chooses to purchase access from the firm that has previously offered the lower price. If both integrated firms offer an identical wholesale price in the first period, the access provider is chosen randomly.

[5]The model assumes that consumers explicitly value variety. With regard to the derivation of the demand structure for varying numbers of active firms in the market see Höffler (2008).

Throughout all experimental sessions, Firm D is modeled to mimic the behavior of a competitive fringe in the retail market that reacts to the price setting by the integrated firms, Firm A and Firm B. It is therefore assumed that Firm D always chooses the best-response retail price, i.e., the price that maximizes its profit given the wholesale and retail prices set by the integrated firms.

In the experiment, prices are scaled as follows: Values obtained by the Shubik and Levitan (1980) model are multiplied by $^{100}/_{0.15}$. and firms can set their prices to any integer in the range of zero to one hundred. In terms of the original Shubik and Levitan (1980) values, this corresponds to the price interval [0;0.15]. As a consequence, the joint profit among integrated firms' is maximized when integrated firms choose maximum prices in both the wholesale market ($a_{max} = 100$) and the retail market ($p_{max} = 100$). Therefore, the JPM outcome is identical across treatments. Moreover, the scaling allows for a more granular representation of the relevant price interval between the theoretically predicted competitive and collusive prices as well as the monopoly price in the case of a single access provider.

In contrast to the theoretical literature on wholesale competition, which usually prescribes a specific temporal sequence of actions, timing of price decisions is endogenized in the experiment by means of a continuous time framework. Endogenous timing of price setting has two aspects: First, no assumption is made on the sequence of upstream and downstream decisions. While it is frequently assumed that wholesale prices are set prior to retail prices (Bourreau et al., 2011), prices may also be chosen simultaneously (Nocke and White, 2007). Second, price setting of the integrated firms at a specific market level is equally unconstrained, i.e., these firms decide not only about the magnitude of a price, but also about timing when to change it. Therefore, the experimental design includes various time settings that are captured by the theoretical literature, but at the same time allows for a more general approach as it also incorporates additional settings that may arise endogenously. In consequence of the endogenous timing induced by the continuous time framework, multiple theoretical predictions may apply, depending on the specific temporal sequence of firms' actions. In order to provide a robust theoretical prediction, consider the following four alternative *timing models*, which are variants of either a sequential-move or a simultaneous-move game proposed in the theoretical literature:

*(1)* Two-stage game as suggested by Bourreau et al. (2011)[6]: First, integrated firms set their wholesale prices simultaneously and the downstream retailer chooses its access provider. Second, all firms decide simultaneously on their retail prices.

*(2)* Three-stage Stackelberg game: Same as (1) with the exception that the downstream retailer chooses its retail price in a third stage, i.e., after the integrated firms have chosen their respective retail prices.

*(3)* Simultaneous-move game as assumed by Nocke and White (2007): All firms set all of their prices, both wholesale and retail, simultaneously.

*(4)* Two-stage Stackelberg game: Same as (3) with the exception that the downstream retailer chooses its retail price in a second stage, i.e., after the integrated firms have chosen their prices.

Table 5.1 denotes theoretical equilibrium predictions for four market scenarios and depicts resulting ordinal differences of wholesale and retail prices for all four timing models. Note that the hypotheses regarding the direction of a price difference hold equally for wholesale and retail prices of each individual firm. Although the timing models vary with regard to the specific numerical predictions for equilibrium prices in the investigated scenarios, the direction of price effects between scenarios align—with one exception that is discussed below.[7]

[6]Note that, in contrast to Bourreau et al. (2011), there is no assumption made that the downstream retailer will always be supplied by at least one integrated firm and therefore consider cases where complete foreclosure may arise as an equilibrium (see Atiyas et al., 2015, for a detailed analysis in context of the Shubik and Levitan model). Integrated firms may choose to set wholesale prices in excess of their own retail prices and consequently foreclose the retailer from the downstream market, which implies $q_D = 0$.

[7]See Appendix A.3 for the complete analysis and a comprehensive comparison of all models.

TABLE 5.1: *Predicted wholesale and retail price differences between market scenarios.*

| | No regulation | | Margin squeeze regulation |
|---|---|---|---|
| Wholesale monopoly | *Monopoly outcome* or *Foreclosure* | $\geq$ <br> $\leq$ | *Constrained monopoly outcome* |
| | $\geq$ | | $>$ |
| Wholesale competition | *Competitive outcome* or *Foreclosure* | $\geq$ | *Competitive outcome* |

In order to allow for a benchmark for the evaluation of wholesale competition, consider first the market outcome under a wholesale monopoly. In this scenario only Firm A offers a wholesale price and may provide the wholesale good to the retailer Firm D. By contrast, Firm B relies on its vertically integrated structure to produce its own wholesale good, but does not offer access to its wholesale resource. In the absence of regulation, given $\gamma = 30$, Firm A is expected to set the wholesale price either at the wholesale monopoly level $a_A = a^m$ or such that the retailer is foreclosed from the downstream market. As shown in Appendix A.3, the latter outcome arises if the retailer's price reaction is not explicitly anticipated by the monopolistic wholesale provider, i.e., in Timing Models (1) and (3). The introduction of margin squeeze regulation changes the equilibrium outcome in the wholesale monopoly scenario only if equilibrium prices of Firm A under no regulation violate the margin squeeze condition $a_A \leq p_A$. Whereas margin squeeze regulation is then expected to decrease prices in comparison to the foreclosure outcome, it instead increases wholesale and retail prices for all firms according to the theoretical prediction in Timing Model (2), where foreclosure does not constitute an equilibrium under no regulation. In sum, theoretical predictions on whether the implementation of margin squeeze regulation decreases prices in a wholesale monopoly are ambiguous.

In the wholesale competition scenario, it is straightforward that symmetric marginal cost pricing, i.e., $a_A = a_B = 0$, is a Nash equilibrium, as is shown by Bourreau et al. (2011). The corresponding equilibrium retail prices are thus symmetric for all three firms. In Timing Models (2) and (4) this equilibrium is unique, because integrated firms anticipate that Firm D as a follower can only act as a price taker and therefore find it always profitable to make a viable wholesale offer.[8] In contrast, in Timing Models (1) and (3), there exists a second foreclosure equilibrium in which both integrated firms decide not to offer a viable wholesale price to the retailer, i.e., the retailer does not supply any retail consumers (Atiyas et al., 2015). Introducing margin squeeze regulation in the case of wholesale competition renders foreclosure impossible, thus, the competitive equilibrium remains as the unique predicted outcome in all presented timing models. In conclusion and in line with previous theoretical analyses, prices under wholesale competition are likely to be below prices in a wholesale monopoly and never exceed them across all model variants.

### 5.2.2 Design

The experimental design is based on a continuous time framework in which participants can observe competitors' price changes immediately and market variables are updated in real time. Similar designs have recently been used in experimental economics, e.g., in the context of a prisoner's dilemma game (Bigoni et al., 2015; Friedman and Oprea, 2012) as well as in a Hotelling setting (Kephart and Friedman, 2015). Next to its property to endogenize the timing of the game and thereby to reconcile different timings proposed in the theoretical literature, the continuous time framework is chosen for the following reasons: First, continuous time is conjectured to promote the emergence of a theoretical prediction in complex market settings (Kephart and Friedman, 2015; Kephart and Rose, 2015). Second, under both Cournot as well as Bertrand competition, Section 3.3 systematically compares the extent of tacit collusion that emerges under continuous time and discrete time and finds lower levels of tacit collusion in continuous time for both competition models. Therefore, the continuous time framework offers a more conservative experimental test of the emergence of tacit collusion than a discrete time framework. Third, through the continuous feedback loop subjects can

[8]Hence, modelling the retailer as a follower in a Stackelberg retail setting may be viewed as an alternative implementation of the a priori assumption made by Bourreau et al. (2011) which guarantees that the integrated firms have no incentive to foreclose the retailer.

directly assess the interdependency between prices in the wholesale and retail market, which aids them in evaluating the impact of their decisions on their individual performance and on aggregate market outcomes.

The experiment is computerized with the *Java*-based experimental software *Brownie* (Müller et al., 2014). The course of the experiment is divided in two phases: the trial phase and the game phase. During the trial phase subjects are able to test various price configurations for all firms in the particular market cohort and to observe the resulting payoffs, while these actions do not impact the subjects' earnings and are not visible to other participants, i.e., the subjects do *not* interact with each other during the trial phase. The game phase, which starts after all subjects confirm their initial prices in the trial phase, lasts for exactly 30 minutes. All decisions in the game phase directly impact the monetary payoff of the subjects. Earnings are the cumulative profits over the time horizon of the experiment. Current profits and cumulative earnings are displayed to subjects over the entire game phase.

As motivated above, the integrated firms, Firm A and Firm B, are represented by human subjects while the downstream retailer, Firm D, is represented by an automated software agent. The agent is programmed to constantly choose its profit-maximizing price given the wholesale and retail prices set by the integrated firms. Thereby, the software agent reacts immediately to any price change made by one of the other firms. In this setup, the experiment covers the following three modes of wholesale competition and two regulatory Open Access regimes in a full-factorial manner, thus ensuing six treatments (see Table 5.2):

*Wholesale Monopoly (WM):* Only Firm A sets a wholesale price and can change it at any time. Firm B does not participate in the wholesale market.

*Wholesale Competition (WC):* Firm A and Firm B set and can change wholesale prices at any time.

TABLE 5.2: *Full-factorial experimental design with six treatments.*

| Treatments | No Regulation | Margin Squeeze Regulation |
|---|---|---|
| Wholesale Monopoly | WM-NR<br>($N$ = 12) | WM-MSR<br>($N$ = 11) |
| Wholesale Competition | WC-NR<br>($N$ = 9) | WC-MSR<br>($N$ = 10) |
| Wholesale Competition with Price Commitment | WCPC-NR<br>($N$ =10) | WCPC-MSR<br>($N$ = 12) |

Independent observations at the market cohort level in parentheses.

*Wholesale Competition with Price Commitment (WCPC))* Firm A and Firm B set wholesale prices, however, each firm's wholesale price is fixed for an embargo period of 30 seconds after it is changed, everything else being equal to *WC*.

*No Regulation (NR):* Firms set wholesale and retail prices freely.

*Margin Squeeze Regulation (MSR):* Firm A and Firm B may set neither their wholesale price above their own retail price nor their retail price below their own wholesale price. If firms set wholesale (retail) prices that violate these conditions, the experimental software displays a warning and sets the price to the allowed maximum (minimum), which is the current own retail (wholesale) price.

### 5.2.3 Procedures

The experimental sessions were conducted with students of the Department of Economics and Management at the Karlsruhe Institute of Technology, Karlsruhe, Germany, who were recruited via the *ORSEE* platform (Greiner, 2015). Overall, 128 subjects participated in the study and each participant played only one of the treatments (between-subject design). The average experimental session lasted 70 minutes. On average, subjects earned a performance-based payment of 16.80 Euro in addition to a base fee of 5 Euro. Participants were randomly assigned to groups of two and interacted with the same firm for the entire time horizon of the experiment (fixed partner matching). Consequently, there are 64 independent observations at the market cohort level as denoted by Table 5.2. The current market data is recorded every 500 ms, thus, there are 3,600 data tuples per market cohort that include wholesale and retail prices as well as the corresponding quantities and profits.

While the main analyses and results will focus on the student sample, a complementary validation study was additionally conducted for the *WCPC-NR* treatment with 16 professional experts in an effort to address external validity concerns. The experts were recruited from the regulatory department of a major German telecommunications operator, where they deal with issues of access regulation on a daily basis. The study was executed under identical conditions as in student experiments with three exceptions. First, the duration of the game phase was shortened to ten minutes. Second, the payment scheme was changed to a lottery system, where participants could win one of three vouchers with a monetary value of 30 Euro each. The number of lottery tickets that participants received were dependent on their payoff in the experiment. By this means, monotonicity was ensured with regard to the relationship between individual performance and payoffs. Third, each participant played a second *WCPC-NR* treatment with a more differentiated retail market ($\gamma = 50$). The sequence of the two treatments was randomized across three experimental sessions.

All experimental sessions with students as well as experts were conducted with the same experimental software and hardware in order to ensure consistency, particularly with regard to the graphical user interface. Each session was run according to the following protocol. Upon entering the laboratory, subjects are randomly assigned to a seat, from which they can neither see nor speak to any other participant of the experiment. Subsequently, the experimental instructions[9] are handed to the participants in print and read aloud from a recording. Paragraphs that are identical across treatments are recorded once and the recording is used in all treatments. Prior to the beginning of the experiment, each subject has to complete a computerized comprehension test that includes a set of questions regarding the experimental instructions and the experimental procedure. Participants are allowed to proceed to the next question only after entering the correct answer to the current one. After all subjects successfully complete the test,

[9]Exemplary instructions for the *WCPC-MSR* treatment are provided in Appendix C.2.

the experiment starts automatically. In addition to this procedure, student participants wore ear protectors from the beginning of the questionnaire until the end of the game phase in order to avoid any influence from clicking noises of computer mouses.

## 5.3 Results

### 5.3.1 Main study

In the following, market prices, firms' profits and consumer welfare are evaluated across treatments for the main study with students. The wholesale market price $a_m$ is given by the wholesale price that the entrant faces, i.e., the minimum of both wholesale offers. The retail market price $\psi_m$ is defined as the transaction price, which is the demand-weighted average of retail prices, i.e., $\psi_m = \sum_k \frac{q_k}{Q} \cdot p_k$ where $Q$ is the aggregate market demand. Profits are given by the amount of money that participants earn during the game phase, i.e., the final payoff excluding the fixed base fee. The average profit of both integrated firms is denoted by $\pi_{AB}$ and the profit of the downstream retailer by $\pi_D$. Consumer surplus is computed as the utility of a representative consumer given the supplied quantities of all three firms subtracted by the transaction price, i.e., $CS = \sum_k q_k - \frac{3}{2(1+\gamma)}(\sum_k q_k^2 + \frac{\gamma}{3}(\sum_k q_k)^2) - \sum_k q_k p_k$ (see Bouckaert and Kort (2014) for a detailed derivation). For ease of interpretation consumer surplus is standardized as $\widetilde{CS} = \frac{CS - CS^{min}}{CS^{max} - CS^{min}}$ on the interval of eligible prices, i.e., $p_k \in [0, 100]$. Thus, $\widetilde{CS} = 0$ denotes the minimum consumer surplus at $p_k = 100$, while $\widetilde{CS} = 1$ represents the maximum consumer surplus at $p_k = 0$. For a focus on market outcomes in a stable market environment and due to the complexity of the experiment start- and endgame effects are neglected by considering only the market data from recorded ticks 601 to 3,000 with 1 tick $= 500$ ms, i.e., the first five and last five minutes are dropped for the subsequent analysis. For the same reasons, the analysis is based on medians as this mitigates the impact of outliers in comparison to averages and should therefore provide a more conservative analysis (see, e.g., Friedman and Oprea (2012) for an identical approach in a continuous time experiment). Arguably, regulators and policy makers should be more

TABLE 5.3: *Treatment median of median market cohort prices, profits and consumer surplus.*

| Treatment | *Markets* | $N$ | $a_m$ | $\psi_m$ | $\pi_{AB}$ | $\pi_D$ | $\widetilde{CS}$ |
|---|---|---|---|---|---|---|---|
| WM-NR | 12 | 28,800 | 73.573 | 65.499 | 16.383 | 0.899 | 0.292 |
| WM-MSR | 11 | 26,400 | 72.572 | 83.124 | 20.750 | 1.028 | 0.153 |
| WC-NR | 9 | 21,600 | 86.085 | 88.407 | 22.434 | 0.258 | 0.097 |
| WC-MSR | 10 | 24,000 | 83.082 | 92.281 | 22.802 | 2.339 | 0.062 |
| WCPC-NR | 10 | 24,000 | 40.540 | 49.560 | 12.243 | 2.491 | 0.461 |
| WCPC-MSR | 12 | 28,800 | 49.049 | 67.415 | 15.866 | 2.322 | 0.298 |
| Total | 64 | 153,600 | 72.071 | 76.159 | 18.093 | 1.672 | 0.213 |

Medians are based on minutes [5,25] of the game phase.

interested in the *median* outcome that can be expected from a single scenario than the *average* effect across multiple co-existing scenarios.[10]

Table 5.3 presents the respective treatment medians of median values at the market cohort level for wholesale and retail prices, firms' profits, and consumer surplus together with the number of independent market cohorts and the number of partially dependent observed time ticks. In addition, Figure 5.2 depicts the period medians of wholesale and retail market prices across individual market cohorts for each of the six treatment combinations. For purposes of illustration, every point in the graphs is a median over 50 subsequent ticks. In order to evaluate treatment effects statistically, consider the following quantile regression (Koenker and Hallock, 2001):

$$\begin{aligned} X_{jt} = \beta_0 + \beta_{Period} \cdot t + \beta_{WC} \cdot WC \\ + \beta_{WCPC} \cdot WCPC \\ + \beta_{MSR} \cdot MSR \\ + \beta_{WCxMSR} \cdot WC \cdot MSR \\ + \beta_{WCPCxMSR} \cdot WCPC \cdot MSR + \epsilon_{jt}, \end{aligned}$$

where $X_{jt}$ denotes the respective market variable $X$ in market cohort $j$ and period $t$. Treatment *WM-NR* is adopted as the baseline.[11] *WC*, *WCPC* and *MSR* are dummy vari-

[10]Nevertheless, the reported results are similar if the analysis is based on means rather than on medians (see Appendix B.2).

[11]Pairwise comparisons between all treatments by means of quantile regressions are reported in Appendix B.2.

FIGURE 5.2: *Median wholesale (dashed) and retail (solid) market prices for each of the six treatments.*

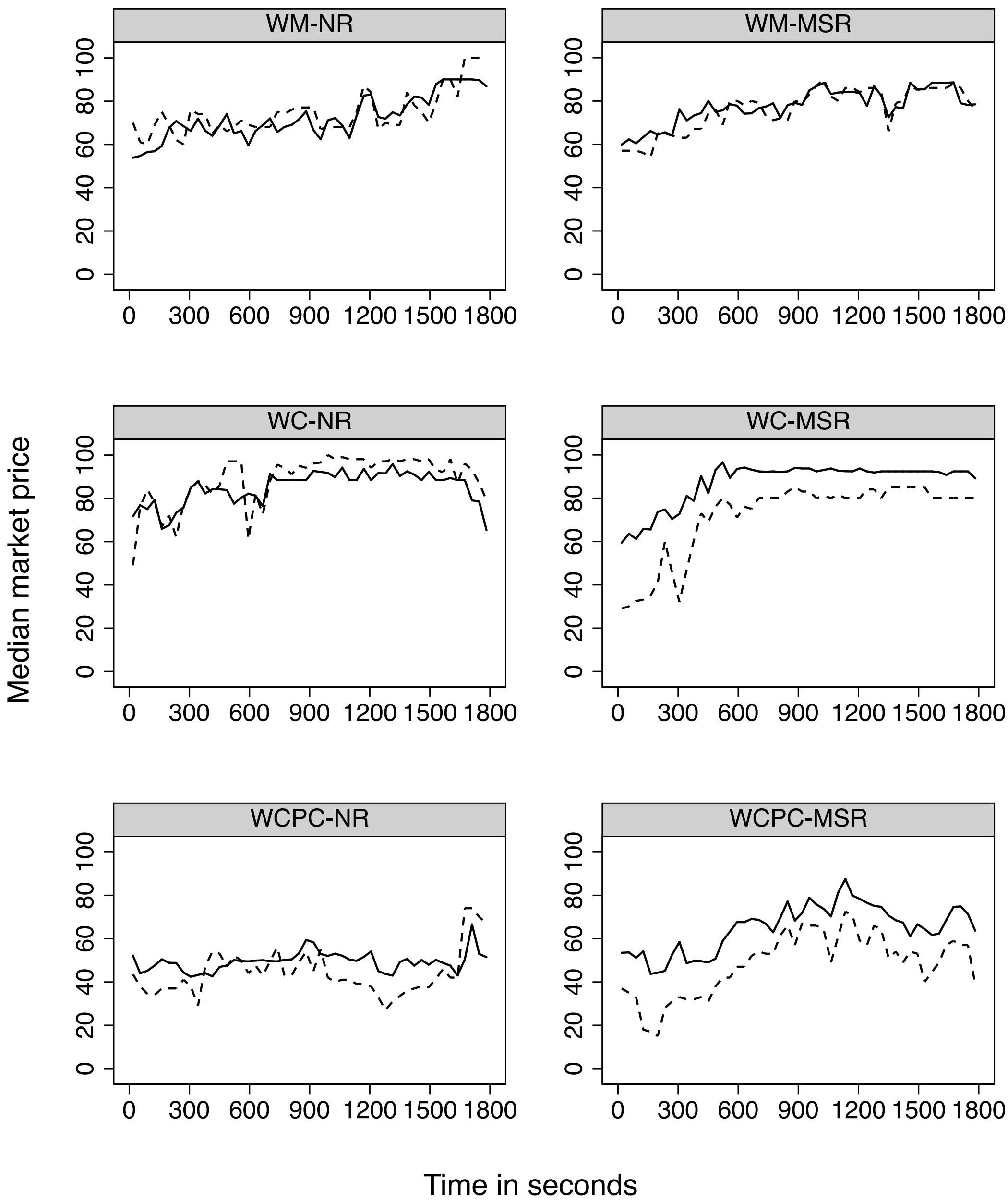


TABLE 5.4: *Quantile regressions of wholesale market price $a_m$, retail market price $\psi_m$, integrated firms' average profit $\pi_{AB}$, retailer's profit $\pi_D$ and consumer surplus $\widetilde{CS}$. Baseline: Wholesale Monopoly & No Regulation (WM-NR).*

| Covariate | (1) $a_m$ | (2) $\psi_m$ | (3) $\pi_{AB}$ | (4) $\pi_D$ | (5) $\widetilde{CS}$ |
|---|---|---|---|---|---|
| Wholesale Competition (WC) | 23.879** (10.073) | 18.376* (9.738) | 4.839*** (1.830) | −0.813 (0.815) | −0.162** (0.080) |
| WC w/ Price Commitment (WCPC) | −28.154*** (8.851) | −19.763** (9.130) | −5.459*** (1.729) | 1.130 (0.861) | 0.212*** (0.077) |
| Margin Squeeze Regulation (MSR) | 9.401 (10.812) | 9.721 (9.927) | 2.358 (1.827) | 0.173 (0.798) | −0.081 (0.078) |
| WC x MSR | −24.309* (13.731) | −7.156 (12.170) | −2.562 (2.403) | 1.924** (0.926) | 0.060 (0.100) |
| WCPC x MSR | −1.928 (17.188) | 7.250 (12.692) | 1.759 (2.774) | 0.019 (0.930) | −0.088 (0.116) |
| Period | 0.004 (0.003) | 0.004** (0.002) | 0.001* (< 0.001) | > −0.001 (< 0.001) | > −0.001** (< 0.001) |
| Constant | 62.893*** (9.764) | 62.972*** (9.148) | 16.251*** (1.931) | 1.324* (0.769) | 0.319*** (0.080) |
| Observations | 153,600 | 153,600 | 153,600 | 153,600 | 153,600 |

Clustered standard errors (by market cohort) in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

ables indicating the respective mode of wholesale market structure and Open Access regulation. Interactions *WC* x *MSR* and *WCPC* x *MSR* delineate the effects of margin squeeze regulation under a specific mode of wholesale competition. Standard errors are clustered on the market cohort level to control for intra-cluster correlation over repeated observations from periods in the same market cohort (Parente and Silva, 2016). The estimates of the respective models for market variables of interest are reported in Table 5.4 and interpreted in the following.

In the benchmark case *WM-NR* the wholesale monopolist sets a positive wholesale price as is indicated by the estimated constant in Model (1), which is similar in magnitude to the retail market price as reported in Model (2). This is in line with the observation that margin squeezes occur frequently, such that the non-integrated firm is *effectively foreclosed*, i.e., the wholesale market price is greater than or equal to the retail prices of both integrated firms.[12] The median rate of foreclosure at the individual market cohort level amounts to 49.52% in this scenario. Still, the profit of Firm D is found to be significantly different from zero, as indicated by the positive constant in Model (4). In other words, even in the case of an unregulated wholesale monopoly, the downstream retailer can profitably participate in the retail market. Due to its access monopoly, Firm A achieves a significantly ($p < 0.01$) higher median profit ($\pi_A = 19.031$) than its integrated competitor ($\pi_B = 14.294$).[13] Note that all of these results are in line with the theoretical prediction.

**RESULT 5.1.** *The introduction of wholesale competition reduces neither wholesale prices nor retail prices. In fact, under homogeneous Bertrand competition at the wholesale level consumers as well as the downstream retailer are worse off compared to the case of an unregulated wholesale monopoly.*

Surprisingly, relative to an unregulated wholesale monopoly, the introduction of homogeneous Bertrand competition at the wholesale level increases both wholesale and retail market prices significantly. While under *WC-NR* the wholesale market price rises by 23.88 pp, consumers face an 18.38 pp higher retail market price in comparison to *WM-NR*. Although it is well-known that Bertrand competition yields supra-competitive prices, it is notable that under *WC-NR* prices are set even significantly above price levels of *WM-NR*. In consequence, the ability to tacitly collude in the wholesale market allows the integrated firms to extract higher profits than in the monopoly treatment as indicated in Model (3). While the effect on the retailer's profit is negative but insignificant, the median rate of foreclosure is 62.46%, and thus higher than under *WM-NR*.

**RESULT 5.2.** *Competition in the wholesale market can be stimulated by introducing competition for the market through a price commitment. Then, wholesale and retail prices are lower than under a wholesale monopoly, but remain above the theoretical prediction.*

[12]Note that the non-integrated firm may still be marginally active in the retail market, because goods are differentiated.

[13]See Appendix B.2 for the corresponding quantile regression.

Remarkably, the collusive effect of wholesale competition is set off by a simple wholesale price commitment for integrated firms. In particular, under *WCPC-NR* the wholesale market price decreases significantly by 28.15 pp (52.03 pp) relative to *WM-NR* (*WC-NR*), while the transaction price in the retail market is lowered significantly by 19.76 pp (38.14 pp). As a result, consumers' surplus increases significantly by 21.2 pp compared to *WM-NR* as indicated by Model (5). In line with declining market prices, the integrated firms' profits decrease significantly as well. Despite lower wholesale prices, the margin between wholesale and retail prices remains relatively slim due to the increasing price competition at the retail level as is depicted by the lower left panel in Figure 5.2. In consequence, the median rate of foreclosure amounts to 29.10%. The effect on the retailer's profit is found to be insignificant, although positive in absolute terms. Evidently, the estimated wholesale access under *WCPC-NR* price of $62.893 - 28.154 = 34.739$ remains well above the theoretical prediction of $a_m = 0$.

**RESULT 5.3.** *There is no evidence that margin squeeze regulation reduces retail prices, and thus consumers do not benefit from such a regulation. However, the introduction of a margin squeeze regulation may reduce wholesale prices, and thus the downstream retailer may be better off.*

As reported above, margin squeezes are frequently observed under all market structures at the wholesale level. Since the primary justification for margin squeeze regulation is the prevention of exclusionary and exploitative abuses (Jullien et al., 2014), its impact on market prices and surplus measures is examined in the following. The regression analyses reported in Table 5.4 reveal that margin squeeze regulation generally does not have a significant impact on market outcomes, but rather tends to increase wholesale and retail prices. In fact, the only reduction in wholesale prices evoked by margin squeeze regulation is found in the case of a particularly collusive wholesale market as under unregulated wholesale competition. More specific, the wholesale price under *WC-MSR* is significantly lower than under *WC-NR*, which is indicated visually by the middle panels in Figure 5.2 and supported empirically by the significant interaction effect *WC x MSR*. Although this effect is paralleled by an increase in the retailer's profit, margin squeeze regulation translates neither into significantly lower retail prices

TABLE 5.5: *Quantile regressions of market outcomes in case of wholesale competition without price commitment.*
*Baseline: Wholesale Competition & No Regulation (WC-NR).*

| Covariate | (1) $a_m$ | (2) $\psi_m$ | (3) $\pi_{AB}$ | (4) $\pi_D$ | (5) $\widetilde{CS}$ |
|---|---|---|---|---|---|
| Margin squeeze regulation (MSR) | $-14.632^{*}$ | 3.909 | $-0.149$ | $2.051^{***}$ | $-0.036$ |
| | (8.254) | (3.528) | (1.034) | (0.520) | (0.030) |
| Period | 0.005 | $< 0.001$ | $< 0.001$ | $> -0.001$ | $> -0.001$ |
| | (0.005) | (0.002) | ($< 0.001$) | ($< 0.001$) | ($< 0.001$) |
| Constant | $85.979^{***}$ | $88.125^{***}$ | $22.068^{***}$ | 0.650 | $0.105^{**}$ |
| | (15.948) | (5.347) | (1.638) | (0.869) | (0.045) |
| Observations | 45,600 | 45,600 | 45,600 | 45,600 | 45,600 |

Clustered standard errors (by market cohort) in parentheses.
$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

nor into significantly higher consumer surplus. Taken together, the empirical results do not provide any evidence that consumers or the retailer generally benefit from a margin squeeze regulation.

In an effort to further investigate the impact of the margin squeeze regulation and to delineate effects on stakeholders under different wholesale competition models, the following (reduced) quantile regression model is estimated for each of the wholesale market structures separately to allow for a pairwise comparison:

$$X_{jt} = \beta_0 + \beta_{Period} \cdot t + \beta_{MSR} \cdot MSR + \epsilon_{jt}.$$

This analysis is of particular interest whenever policymakers are able to prescribe rules that govern the competition at the wholesale level but may find themselves unable to change the market structure completely. In these cases the margin squeeze condition may be considered as an ex ante regulatory remedy or as an ex post competition policy instrument. The effect of margin squeeze regulation is therefore examined under all three considered wholesale market structures. First, in the case of a wholesale monopoly, margin squeeze regulation has a positive yet insignificant effect for all price and profit variables, while the corresponding coefficient for consumer surplus is nega-

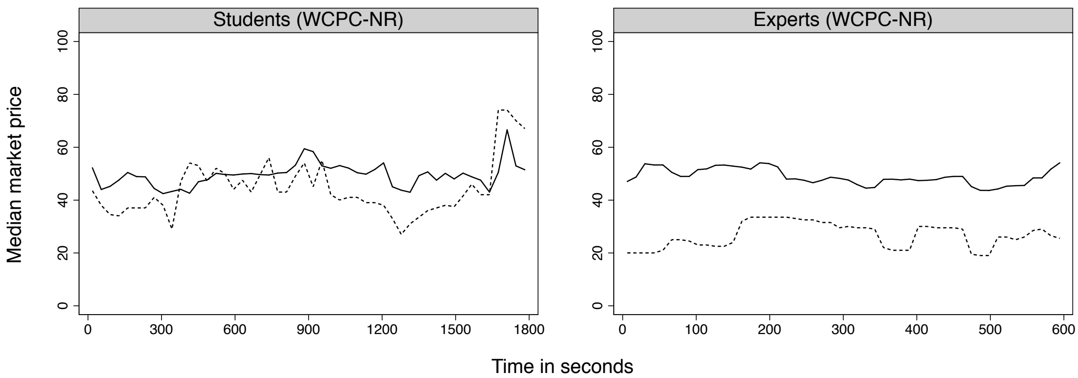
TABLE 5.6: *Quantile regressions of market outcomes in case of wholesale competition with price commitment.*
*Baseline: Wholesale Competition with Price Commitment & No Regulation (WCPC-NR).*

| Covariate | (1) $a_m$ | (2) $\psi_m$ | (3) $\pi_{AB}$ | (4) $\pi_D$ | (5) $\widetilde{CS}$ |
|---|---|---|---|---|---|
| Margin squeeze regulation (MSR) | 7.983 | 17.081** | 4.157* | 0.188 | −0.165** |
| | (10.883) | (8.071) | (2.251) | (0.474) | (0.080) |
| Period | 0.003 | 0.006* | 0.001 | $> -0.001$ | $> -0.001$* |
| | (0.004) | (0.003) | (0.001) | ($< 0.001$) | ($< 0.001$) |
| Constant | 37.475*** | 39.162*** | 10.374*** | 2.335*** | 0.572*** |
| | (8.131) | (5.664) | (1.921) | (0.609) | (0.058) |
| Observations | 52,800 | 52,800 | 52,800 | 52,800 | 52,800 |

Clustered standard errors (by market cohort) in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

tive and insignificant (see Appendix B.2). In line with the theoretical prediction, margin squeeze regulation therefore does not seem to represent a suitable safeguard for effective competition nor a beneficiary instrument for consumers in the case of a wholesale monopoly when an integrated competitor is present. Second, in the case of wholesale competition (Table 5.5), margin squeeze regulation instead significantly reduces the wholesale market price, which resembles the net effect of the general margin squeeze impact, *MSR*, and the interaction effect *WC x MSR* reported in Table 5.4. The pairwise comparison likewise confirms the positive and significant impact on the retailer's profit compared to the unregulated regime. Again, there is no significant negative impact on the retail market price. Accordingly, the effect on consumer welfare is also insignificant. Therefore, it is concluded that the decline of the wholesale market price that results from margin squeeze regulation allows the retailer to increase its profitability, but retail prices do not decrease proportionately and hence, consumers are not better off. Third, in the case of wholesale competition with price commitment, a positive and significant effect on the retail market price (Table 5.6) advises further skepticism with regard to margin squeeze regulation and its impact on consumers. The magnitude of the relative price increase is estimated at 17.08 pp. The price increase benefits the integrated firms by means of significantly higher profits, whereas the effect on the downstream retailer's profit is insignificant. In sum, a margin squeeze regulation is clearly detrimental

FIGURE 5.3: *Median wholesale (dashed) and retail (solid) market prices of students and experts.*




to consumers' interest in this scenario as consumer surplus decreases significantly by 16.53 pp and may therefore even offset the gains from wholesale competition with price commitment. For completeness, a summary of all pairwise comparisons between the treatments by means of quantile regressions is given in Appendix B.2.

### 5.3.2 Validation study

Figure 5.3 illustrates the median wholesale and retail prices under *WCPC-NR* both for the students treatment (left-hand panel) and for the experts treatment (right-hand panel). While wholesale market prices of experts are lower according to the median value over all periods ($a_m^{Students} = 43.043$, $a_m^{Experts} = 29.029$), retail market prices are almost identical ($\psi_m^{Students} = 50.326$, $\psi_m^{Experts} = 50.613$). Note that for both subject pools wholesale prices are different from zero which is the theoretical prediction.

First, market outcomes between experts and students are compared based on the entire time horizon of the experiment. In particular, the null hypothesis is that the median market prices in the students sample and the median market prices in the experts sample are from populations with the same distribution. According to a Mann-Whitney U test, there is no significant difference in wholesale market prices ($z = 1.42$, $p = 0.155$) nor in retail market prices ($z = 0.71$, $p = 0.477$). Also with respect to overall medians, i.e., the median of market cohort medians, Fisher's exact test does not reject the equality of me-

TABLE 5.7: *Quantile regressions of market outcomes on subject type in case of wholesale competition with price commitment.*
*Baseline: Wholesale Competition with Price Commitment & No Regulation (WCPC-NR) with Students.*

| Covariate | (1) $a_m$ | (2) $\psi_m$ | (3) $\pi_{AB}$ | (4) $\pi_D$ | (5) $\widetilde{CS}$ |
|---|---|---|---|---|---|
| Experts | $-14.465$ | 1.170 | $-0.613$ | 1.839*** | 0.003 |
| | (10.259) | (10.908) | (2.923) | (0.600) | (0.126) |
| Period | 0.001 | 0.003 | 0.001 | $< 0.001$ | $> -0.001$ |
| | (0.011) | (0.008) | (0.002) | ($< 0.001$) | ($< 0.001$) |
| Constant | 42.297*** | 48.270*** | 11.974*** | 2.043*** | 0.477*** |
| | (9.791) | (6.920) | (2.179) | (0.427) | (0.078) |
| Observations | 21,618 | 21,618 | 21,618 | 21,618 | 21,618 |

Clustered standard errors (by market cohorts) in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

dian market prices at the wholesale level ($p = 0.637$) or the retail level ($p = 1.0$). Finally, the same result is obtained by a quantile regression that investigates the differences of the subject pools while controlling for the time trend and intra-cluster correlation. In order to obtain a comparable data basis with an equivalent number of periods for the experts and students treatments, the measures of the students treatments are averaged over three subsequent 500 ms intervals. As shown in Table 5.7, the effect of the expert subject pool is insignificant for all market variables except the retailer's profit. The higher profit of the entrant can be attributed to a larger spread between wholesale and retail prices in a subset of individual market cohorts in the experts treatment, which is also indicated by the negative coefficient for the median wholesale market price.

Naturally, general and conclusive evidence cannot be derived based on findings of statistical insignificance. However, in addition to the finding of statistical indifference, descriptive measures as portrayed in Figure 5.3 show quantitatively similar and qualitatively equal behavior for both subject pools.

## 5.4 Repeated game analysis of tacit collusion incentives

In an effort to relate the empirical findings of the experiment to the four timing models introduced in Section 5.2, their theoretical predictions are considered in a repeated game context. Thereby, a comparison to observed experimental results may reveal which of the timing models best captures endogenous timing under the continuous time framework. Considering the benchmark scenario of an unregulated wholesale monopoly, observed wholesale prices suggest that the wholesale provider does generally not foreclose the downstream retailer, but rather charges the monopolistic wholesale price. Moreover, there is no evidence that margin squeeze regulation reduces wholesale prices in the monopoly scenario. Both observations are in line with predictions by Timing Models (2) and (4) and contradict predictions by Timing Models (1) and (3). This may be considered as support for the experimental design as it is in line with the intention to model the non-integrated retailer as a competitive fringe, whose reaction is immediate, but subsequent and anticipated by the integrated firms. Furthermore, median prices for all wholesale competition treatments are significantly above the competitive outcome, which is an equilibrium in all timing models. More specific, the significant increase in wholesale and retail prices from wholesale monopoly to wholesale competition contradicts the consensus prediction. Whereas wholesale prices close to $a_{max} = 100$ may be interpreted as an indication for the foreclosure outcome, which is predicted by Timing Models (1) and (3), observed retail prices close to $p_{max} = 100$ are in line with the JPM outcome, but diverge from predicted retail prices in the foreclosure outcome. This suggests the presence of substantial tacit collusion among integrated firms in the wholesale competition scenario.

Although experiments in continuous time have thus far been primarily used to consider static one-shot games (Friedman and Oprea, 2012; Bigoni et al., 2015; Kephart and Friedman, 2015), continuous time may also be interpreted as an infinite repetition of a one-shot game as described by the timing models. In this context, the incentives to tacitly collude in the upstream market can be compared in the spirit of Nocke and White (2007) and Normann (2009) with respect to the critical discount factor that is required

TABLE 5.8: *Profits and discount factors under wholesale monopoly.*

| | Firm A | | | | Firm B | | | |
|---|---|---|---|---|---|---|---|---|
| Timing Model | $\pi_A^{JPM}$ | $\pi_A^{Dev}$ | $\pi_A^{Punish}$ | $\delta_A$ | $\pi_B^{JPM}$ | $\pi_B^{Dev}$ | $\pi_B^{Punish}$ | $\delta_B$ |
| (1) | 34.00 | 35.02 | 15.04 | 0.05 | 17.00 | 25.40 | 15.04 | 0.81 |
| (2) | 34.00 | 35.02 | 15.61 | 0.05 | 17.00 | 25.40 | 14.05 | 0.74 |
| (3) | 34.00 | 35.02 | 15.04 | 0.05 | 17.00 | 25.40 | 15.04 | 0.81 |
| (4) | 34.00 | 35.02 | 15.07 | 0.05 | 17.00 | 25.40 | 11.86 | 0.62 |

TABLE 5.9: *Profits and discount factors under wholesale competition.*

| | Firm A | | | | Firm B | | | |
|---|---|---|---|---|---|---|---|---|
| Timing Model | $\pi_A^{JPM}$ | $\pi_A^{Dev}$ | $\pi_A^{Punish}$ | $\delta_A$ | $\pi_B^{JPM}$ | $\pi_B^{Dev}$ | $\pi_B^{Punish}$ | $\delta_B$ |
| (1), (2), (3), (4) | 25.50 | 30.21 | 5.79 | 0.19 | 25.50 | 30.21 | 5.79 | 0.19 |

to sustain collusive outcomes. Assuming a grim trigger strategy, deviations from JPM prices $a_{max}$ and $p_{max}$ are punished by infinite play of the competitive Nash equilibrium (cf. Nocke and White, 2007). Individual discount factors that support collusive behavior are computed by $\delta_i = \frac{\pi_i^{Dev} - \pi_i^{JPM}}{\pi^{Dev} - \pi_i^{Punish}}$ for $i \in \{A, B\}$, where $\pi^{JPM}$ is the firm's share of the JPM profit, $\pi^{Dev}$ is the maximum deviation profit that a firm can achieve by unilateral deviation, and $\pi^{Punish}$ is the firm's profit in periods after deviation (cf. Normann, 2009). The minimum critical discount factor is then given by $\delta = \max\{\delta_A, \delta_B\}$.

Following this approach, the minimum critical discount factors can be computed for wholesale monopoly and competition. Table 5.8 denotes the respective profits and discount factors for both integrated firms in case of a wholesale monopoly for each timing model. Likewise, Table 5.9 states profits and discount factors under wholesale competition. Here, critical discount factors are identical across all timing models, because in each model punishment is exercised through the competitive equilibrium. Moreover, integrated firms' critical discount factors under wholesale competition are symmetric because collusive and deviation profits are calculated as expected values, i.e., firms expect to be the access provider with probability one half.[14]

[14] Alternatively, one may assume that firms gain the entire wholesale profit if they deviate. Irrespective, the ensuing minimum critical discount factor $\delta = 0.43$ is still lower than the ones reported in Table 5.8.

Pairwise comparisons of minimum critical discount factors under wholesale monopoly and competition show that collusion is sustainable for a larger range of discount factors under wholesale competition, independent of the assumed timing of the one-shot game. More specifically, Firm B has a stronger incentive to deviate in the case of a wholesale monopoly, because foregone profits in the case of punishment are relatively low compared to its JPM profit share. In contrast, in the case of wholesale competition, expected JPM profits are higher, while profits in the case of punishment are lower, thus making a deviation less attractive. Therefore, tacit collusion is less likely in the wholesale monopoly setting than in the wholesale duopoly setting. This may provide a theoretical rationale for Result 1.

However, notice that this does not provide a rationale for Result 2, because the same theoretical analysis applies to the case of wholesale competition with price commitment. To see this, consider price commitment to induce sequential-move rather than simultaneous-move interaction between the integrated firms regarding the wholesale price.[15] Evidently, this does not apply to the wholesale monopoly scenario and it is easy to see that this would also not change the equilibrium in the wholesale competition scenario: As each of the integrated firms has an incentive to be the access provider, the first mover will anticipate to be undercut by the second mover and thus set the minimum feasible access price, just like when access prices are determined simultaneously. Consequently, the alternative timing would result in the same critical discount factors and therefore the same prediction with respect to the incentives for tacit collusion. From a more behavioral perspective, one could argue that the price commitment limits the extent to which one of the integrated firms can immediately retaliate the other (in the sense of the grim trigger strategy), which therefore makes the punishment less severe, and ultimately tacit collusion less likely. However, in an infinitely repeated game this lack of punishment in a short (finite) period does not matter.[16] But from a behavioral

[15]Note that this timing makes sense only in Timing Models (1) and (2), because it is the very nature of Timing Models (3) and (4) that integrated firms' decisions are made simultaneously in the upstream and downstream markets.

[16]Obviously, it would matter in a finitely repeated game. However, note that in this case the only subgame-perfect equilibrium would also be to play the (unique) equilibrium of the one-shot game in each period. That is, for the case of wholesale competition, and irrespective of a price commitment, the

perspective it may. After all the price commitment is able to secure the second-mover a guaranteed wholesale profit for a (short) period of time and as such, it may stimulate a notion of *competition for the market* that—in line with Result 2—amplifies the competitive process.

## 5.5 Discussion

Although the regulation of access to an essential upstream resource is a perennial issue for policymakers and industry stakeholders, the competitive supply of the bottleneck resource by vertically integrated firms is investigated only recently in the theoretical economic literature. By means of an economic laboratory experiment this study scrutinizes these theoretical analyses, particularly with respect to the effectiveness of wholesale competition in the relevant case when there are only two access providers. The results indicate that wholesale duopoly markets may be severely affected by high levels of tacit collusion, such that market performance in terms of market prices and consumer surplus is worse than with a single access provider (Result 5.1). In particular, this is found to be the case under standard homogeneous Bertrand competition at the wholesale level, which is frequently assumed in the theoretical investigations (e.g., Bourreau et al., 2011, 2015). In this vein and in the spirit of a more *behaviorally oriented regulation* (Normann and Ricciuti, 2009; Lunn, 2014), this experimental analysis serves as a regulatory testbed, which points at possible behavioral issues that may arise in practice. After all, in light of the tremendous impact that regulatory decisions have on the respective industry and—especially in the case of network industries—also on other industries, policymakers should be particularly mindful when theoretical predictions are not confirmed in the laboratory. In the present context, a simple price commitment rule significantly improves market outcomes, although the competitive intensity in the wholesale market remains below the theoretical prediction (Result 5.2). Furthermore, in reference to the theoretical analyses by Petulowa and Saavedra (2014) and

competitive outcome would be played. Consequently this model variant does not provide a theoretical rationale for Result 2 either.

Jullien et al. (2014), the experimental results give a clear indication regarding the theoretically ambiguous effect of margin squeeze regulation on retail prices in the presence of wholesale competition by vertically integrated firms. More specifically, the experimental evidence supports the rationale that the ban of a margin squeeze can impede the intensity of competition in the retail market (Result 5.3). Moreover, the experiment points to a particular problem of applying the margin squeeze rule to an environment of multiple firms operating in the wholesale and retail market: When tacit collusion in the wholesale market is stable and leads to prices above the Nash equilibrium, retail pricing is constrained correspondingly. Especially the integrated firm, which naturally has an incentive to be more aggressive in the retail market because it is not affected by the softening effect, may be restricted in setting lower retail prices as long as it decides not to undercut prices in the wholesale market. Although the margin squeeze rule, as an implicit Open Access rule, ensures non-discrimination between competitors, the premise to treat all market participants alike is not aligned with the diverse incentives that occur in the case of simultaneous retail and wholesale competition, e.g., due to the consideration of opportunity costs by the access provider. Thus, non-discrimination of competitors may not always be in the best interest of the consumer.[17]

With respect to the limitations of the experimental study, it should be noted that firms' investment incentives are not considered under the various market scenarios and thus, experimental insights are constrained to short-term issues of static efficiency. However, in many industries, particularly in network industries such as telecommunications, dynamic efficiency is considered to be at least equally important by policymakers. Nevertheless, the findings may still be informative in this context, as there is generally an inherent trade-off between static and dynamic efficiency (see Chapter 2) with some notable exceptions (Klumpp and Su, 2010). That is, dynamic investment incentives are to a large extent influenced by the expectations about the future (static) benefits that arise from a given market structure (especially the market shares of competitors, see Klumpp and Su, 2015), the obtained results may inform further research regarding

[17]Note that an additional well-known negative effect of non-discrimination on competition is articulated by the theory of *restoring monopoly power* (Rey and Tirole, 2007b), where non-discrimination allows the upstream firm to resolve its commitment problem.

the effects that arise under infrastructure-based competition with multiple wholesale providers. In this context, the experimental results also cast doubt on the premise that infrastructure-based competition should be the undisputed regulatory goal (Cave and Vogelsang, 2003; Cave, 2006a), particularly when Open Access for independent retailer is required at the same time (e.g., as indicated by the European Commission's (2014b) digital agenda). This is in line with empirical findings by Höffler (2007) which suggest that infrastructure duplication costs may be higher than the gains from (supposedly) intensified competition. More general with respect to economic experimentation, a second concern arises with respect to the external validity of findings, although the validation study with industry professionals corroborates the robustness of the obtained student subject pool results. Naturally, experimental results do not directly carry over to actual markets, however, at the same time, one should also be cautious to believe that theoretical predictions will hold in practice when they already fail in a laboratory environment. Furthermore, note that the results are based on the relative differences between treatments and should thus not be affected by factors that are held constant across treatments. Nevertheless, an empirical field study of wholesale access in context of infrastructure competition would certainly represent a highly valuable contribution complementing theoretical and experimental work.

Finally, this study may also inspire future work. First, rules and remedies that are deemed to intensify competition at the wholesale level could be investigated in further depth. While two alternative modes of wholesale competition which yield market outcomes below and above the wholesale monopoly treatment have been considered, the investigation of the underlying competitive process and further investigation of instruments that may intensify competition at the wholesale level appear promising. Second, the presented analysis may be extended by a variation of the number of competitors and retailers as well as the introduction of asymmetry between the integrated firms. With regard to the competition across different access levels and quality layers—as in Internet and telecommunications markets—such an extension could provide valuable insight for decision makers and regulators within these fast-moving industries.

# Chapter 6

# Number Effects and Tacit Collusion in Oligopolies

IN oligopolistic markets, concerns about market power and coordinated behavior frequently confront competition and regulatory authorities with the question: *How many competitors are enough to ensure competition*? Thereby, it is of particular interest how the competitiveness of a market is affected if a low number of competitors is further reduced through consolidation, i.e., if the number of firms is reduced from four to three or from three to two. For example, several high-profile merger control proceedings in the European Union[1] as well as in the US[2] have dealt with cases that would reduce the remaining number of competitors from four to three major mobile telecommunications operators in the respective relevant market. In the US airline industry, the Department of Justice had initially filed a lawsuit to block the merger between American Airlines and US Airways that reduced the number of legacy carriers from four to three, explicitly referring to the low number of competitors as a critical threat to effective competition (Stewart, 2013). Even in a high-tech commodity industry like the hard disk drive industry, consolidation among manufacturers raises the question whether there is a mag-

This chapter is based on joint work with Niklas Horstmann and Jan Krämer (Horstmann et al., 2016b).

[1] Hutchinson 3G Austria / Orange Austria (European Commission, 2012), Telefónica Deutschland / E-Plus (European Commission, 2014c), Hutchinson 3G UK / Telefónica Ireland (European Commission, 2014d).

[2] AT&T / T-Mobile US (Federal Communications Commission, 2011), Sprint Corp / T-Mobile US (Federal Communications Commission, 2014).

ical number to reconcile scale synergies and pro-competitive effects (Igami and Uetake, 2015). Similar to competition authorities, sector-specific regulatory agencies implicitly or explicitly examine the sufficient number of competitors when assessing the need for ex ante access regulation. For instance, geographically segmented deregulation of the wholesale broadband access market in the UK is conditioned on the number of active competitors in a region (Ofcom, 2014). Likewise, in media retail markets, which in some countries are characterized by repeated direct public intervention, competition authorities are required to determine the sufficient number of local sellers to achieve sustainable coverage in combination with competitive prices (Balmer, 2013).

In general, the number of firms in a specific market is determined endogenously by the competitive process and particularly by firms' entry and exit decisions. However, as described above, in merger cases and regulatory proceedings, authorities are often required to determine a specific number of competitors exogenously. This makes it necessary to estimate the impact of number effects on the competitiveness in that market. Obviously, markets in practice exhibit many idiosyncrasies that impact competitiveness and require a case-by-case analysis before a merger can be cleared or before regulatory remedies are imposed or lifted. Yet, a general relationship between the number of competitors and the competitiveness of a given market, above and beyond any market peculiarities, is frequently assumed. To this end, it is well-known that equilibrium predictions for market prices (quantities) are generally decreasing (increasing) with a higher number of competitors, i.e., markets become more competitive. However, the impact on the *degree of tacit collusion*, i.e., the ability of firms to sustain a supra-competitive outcome above (below) the equilibrium, is not as clear.

Based on three complementary studies this chapter investigates the research hypothesis that tacit collusion in oligopolistic markets with two, three, and four competitors decreases strictly monotonically with the number of competing firms. From a methodological point of view, experimental laboratory experiments are well suited to address this question, because they allow to observe out-of-equilibrium behavior while controlling for environmental conditions. In this context, it has previously been concluded that tacit collusion is "frequently observed with two sellers, rarely in markets with three sellers, and almost never in markets with four or more sellers" (Potters and Suetens, 2013, p.17). Surprisingly, a review of the extant literature shows that there is actually no robust empirical evidence that would support the claim of a strictly monotonically decreasing relationship between the number of firms and the degree of tacit collusion in a given market. Whereas, a meta-analysis of the extant literature supports the notion that duopolies are significantly more prone to tacit collusion than quadropolies, i.e., that "two are few and four are many" (Huck et al., 2004b, p.435), there is no empirical support for a significant effect when moving from *four to three* firms. However, the lack of statistical power across and within existing studies precludes a conclusive evaluation of a strictly monotonic relationship between the number of firms and the degree of tacit collusion in a market. Moreover, the review of the extant literature reveals a lack of systematic evaluation of such number effects under different competition models (Cournot vs. Bertrand), symmetric and asymmetric firms, and under consideration of different theoretical equilibrium predictions (Nash vs. Walras). Therefore, two laboratory experiments are conducted in this chapter, which are explicitly designed to systematically test for number effects on tacit collusion under price and quantity competition, as well as with symmetric and asymmetric firms. Thereby, the findings show a significant competitive effect from *four to three* firms as well as from *three to two* firms. In fact, the empirically observed decrease in the degree of tacit collusion is almost identical from four to three as from three to two, suggesting a *linear number effect* for highly concentrated oligopolies with regard to the (in)ability to coordinate above the theoretical Nash prediction.

The remainder of this chapter is organized as follows. Next, Section 6.1 reviews the extant experimental literature and conducts a meta-analysis. In Sections 6.2 and 6.3 the design and results of the experiments with symmetric and asymmetric firms are reported, respectively. Section 6.4 discusses the findings pooled over all three studies and highlights their policy implications for both antitrust and regulatory authorities.

## 6.1 Review and meta-analysis of the experimental literature

In order to investigate the general relationship between the number of competitors and the competitiveness in a given market, economic laboratory experiments are particularly suited, because they allow to identify systemic effects and to isolate distinct sources for tacit collusion through controlled variation of exogenous variables (see Section 3.2). In particular, experiments allow to isolate the effect of the number of competitors on firms' ability to coordinate through randomization, while holding constant any potential confounding variable. By this means, the experimental method avoids endogeneity concerns (e.g., of the observed number of competitors) inherent to field data (Angrist and Pischke, 2010), which are especially pronounced in the context of the structure-conduct-performance paradigm (Scherer and Ross, 1990; Schmalensee, 1990) of industrial organization. Moreover, empirical field studies are naturally framed in a specific market context and are thus neither generalizable per se nor directly applicable to other market scenarios as causal relationships are inherently difficult to prove (see Einav and Levin, 2010, for a discussion of generalizability of empirical industry studies). Particularly with regard to the issue of tacit collusion, which is notoriously hard to detect in field studies, laboratory experiments can provide general insights by analyzing in- and out-of-equilibrium strategies and respective market outcomes relative to benchmark equilibria predicted by economic theory.

Consequently, it is not surprising that there are several experimental studies that investigate the drivers and impediments of tacit collusion in oligopolies. In their overview on these experiments, Potters and Suetens (2013) conclude, among others, that "the scope of collusion is strongly affected by the number of competitors" (p.17). With respect to the effect of the number of competitors on tacit collusion, Potters and Suetens suggest a strictly monotonic relationship, referring to individual experimental studies that have employed posted-offer markets, Bertrand competition or Cournot competition. Although several of these studies find that tacit collusion is generally lower for a larger number of competitors, e.g., in markets with four relative to two competitors (e.g., Huck et al., 2004b; Orzen, 2008), as described above, evidence for the stipulated monotonic number effect is rather scarce, in particular with regard to the assessment of tacit collusion in markets with three and four competitors.

### 6.1.1 Experimental designs

Most oligopoly experiments implement one of the two workhorse models in industrial organization: price competition à la Bertrand (Fouraker and Siegel, 1963; Dolbear et al., 1968; Dufwenberg and Gneezy, 2000; Orzen, 2008; Davis, 2009; Fonseca and Normann, 2012) or quantity competition à la Cournot (Fouraker and Siegel, 1963; Bosch-Domènech and Vriend, 2003; Huck et al., 2004b; Waichman et al., 2014).[3] A third strand of literature observes tacit collusion in posted-offer markets, i.e., simultaneous competition in prices and quantities (Ketcham et al., 1984; Alger, 1987; Brandts and Guillén, 2007; Ewing and Kruse, 2010). As the latter experiments use very diverse models and are hence hardly comparable to one another, the focus here is on price or quantity competition. Table 6.1 lists the ten oligopoly experiments which are surveyed in this meta-analysis and which all vary the number of competitors $n$ in a market in one way or another.[4]

Six experiments employ price competition. Four of those investigate homogeneous Bertrand competition, i.e., firms' products are perfect substitutes. The remaining two experiments use differentiated price competition, i.e., competitors' products are differentiated with regard to quality or consumers have heterogeneous preferences: Dolbear et al. (1968) consider a model in which the cross-price elasticity is half the own-price elasticity and Orzen (2008) models a fraction of consumers to be price-insensitive "convenience shoppers" (Orzen, 2008, p.392). All of the four quantity competition experiments included in this meta-analysis employ a homogeneous Cournot model.

[3]Note that merger experiments induce asymmetry exogenously (see Götte and Schmutzler, 2009, for a comprehensive review) or endogenize merger formation which yields asymmetric markets post-merger (Lindqvist and Stennek, 2005). In order to prevent path dependencies from merger formation, only data from those experimental studies that vary the number of competing firms exogenously across treatments is used for this meta-analysis.

[4]To the extent of the author's knowledge, the list in Table 6.1 is complete with the exception of Abbink and Brandts (2005, 2008) for which no complete experimental data was attainable.

TABLE 6.1: *Economic laboratory experiments that vary the number of competing firms.*

| Study | Competition | Information: Complete | Information: Perfect | Matching | $n$ |
|---|---|---|---|---|---|
| | | Bertrand (price) competition | | | |
| Fouraker and Siegel (1963) | Homogeneous | ✓ | ✓/ ✗ | Partner | {2,3} |
| Dolbear et al. (1968) | Differentiated | ✓/ ✗ | ✓ | Partner | {2,4,16} |
| Dufwenberg and Gneezy (2000) | Homogeneous | ✓ | ✓ | Stranger | {2,3,4} |
| Orzen (2008) | Differentiated | ✓ | ✓ | Partner, Stranger | {2,4} |
| Davis (2009) | Homogeneous | ✓/ ✗ | ✓ | Partner | {2,3,4} |
| Fonseca and Normann (2012) | Homogeneous | ✓ | ✓ | Partner | {2,4,6,8} |
| | | Cournot (quantity) competition | | | |
| Fouraker and Siegel (1963) | Homogeneous | ✓ | ✓/ ✗ | Partner | {2,3} |
| Bosch-Domènech and Vriend (2003) | Homogeneous | ✓/ ✗ | ✓ | Partner | {2,3} |
| Huck et al. (2004b) | Homogeneous | ✓ | ✓/ ✗ | Partner | {2,3,4,5} |
| Waichman et al. (2014) | Homogeneous | ✓ | ✓/ ✗ | Partner | {2,3} |

✓: applicable | ✗: not applicable | ✓/ ✗: both (as treatment variable)

Experiments differ further in the amount of information provided to participants. In a situation of complete information, each firm, represented by an individual participant, knows about (or can retrieve) the cost and demand function of all firms in the market. Moreover, a firm with perfect information can observe all decisions made by its competitors, and hence, has knowledge over the full history of the game. Lastly, all but one study employ a fixed matching of firms over the entire time horizon. Instead, Dufwenberg and Gneezy (2000) match firms randomly in each period. Orzen (2008) additionally compares partner and stranger matching in a between-subject manner.

### 6.1.2 Measuring competitiveness as the degree of tacit collusion

In order to compare number effects on competitiveness or likewise, tacit collusion, across heterogeneous data sets from different experimental designs, a uniform performance criterion is required. As absolute price or quantity levels are inconclusive across experiments, different metrics are proposed in the extant literature to measure competitiveness in experimental oligopoly outcomes. For a review of Cournot experiments, Huck et al. (2004b) report the ratio between a market's average total quantity $\overline{Q}$ and the total Nash quantity $Q^{Nash}$, $r = \overline{Q}/Q^{Nash}$. However, as Engel (2007) points out, $r$ is "sensitive to arbitrary changes in the level of $Q^{N[ash]}$" (p.494). In addition, the measure is not well suited to quantify and compare non-equilibrium outcomes between treatments and experimental designs, because it does not incorporate the joint profit maximizing (JPM) outcome as a second benchmark.

Therefore, the measure introduced in Subsection 3.3.2, which has previously been employed in meta-analyses by Engel (2007) and by Suetens and Potters (2007), is utilized here as well. Thus, tacit collusion is measured as the relative deviation of average price from the theoretical equilibrium $E \in \{Nash, Walras\}$ towards the JPM price $p^{JPM}$. Formally,

$$\varphi^E = \varphi_p^E = \frac{\overline{p} - p^E}{p^{JPM} - p^E}.$$

In this vein, $\varphi^E$ represents the *degree of tacit collusion* based on prices as compared to either the Nash equilibrium or the Walrasian (competitive) equilibrium as the theoretical prediction. The Walrasian equilibrium assumes all competitors to be price-takers and thus, under homogeneous Bertrand competition the Nash prediction and the Walrasian prediction coincide. Moreover, under some regularity conditions, Walrasian prices cannot exceed Nash prices in any oligopoly competition model, i.e., $p^{Walras} \leq p^{Nash}$. If $\varphi^E = 0$, the average market price $\overline{p}$ corresponds to the theoretical prediction by the equilibrium concept $E$. If $\varphi^E = 1$, the market is completely collusive and competitors behave like in the case of a monopoly. Note that $\varphi^E$ may exceed one if joint profit is not monotonic in prices; the measures' lower limits, however, depend on the experimental design. Suetens and Potters (2007) employ the same collusion metric based on Nash predictions to investigate relative differences of tacit collusion under Bertrand and Cournot competition.[5]

In addition, Friedman (1971) suggests a theoretical benchmark to assess the likelihood "that tacit collusion can be sustained as an equilibrium in an infinitely repeated game context as part of a grim trigger strategy" (Suetens and Potters, 2007, p.73), which is given by $Friedman = \frac{\Pi^{JPM} - \Pi^{Nash}}{\Pi^{Defect} - \Pi^{JPM}}$ with $\Pi^{Defect}$ as the maximum profit for a firm that unilaterally deviates from a collusive agreement. Hence, the Friedman index measures the incentive to tacitly collude by comparing the collusive markup on the Nash profit

[5] Suetens and Potters (2007) exclude negative prices in Cournot experiments from their calculation of the degree of tacit collusion. In this meta-analysis, however, negative prices are considered as well, as they correctly reflect the high competitiveness of excess capacity in Cournot markets.

to the additional profit for defecting from cooperation. In repeated oligopoly experiments each firm has to trade off short-term profits from deviating to foregone profits in future periods. The higher the Friedman index, the less profitable is a deviation from a collusive agreement.[6] Although the Friedman index assumes an infinitely repeated game, it may nonetheless be informative in the context of finitely repeated games in experiments with fixed lengths across treatments as it is well-known that tacit collusion is no phenomenon that is limited to experiments with random termination rules.

### 6.1.3 Results of the meta-analysis

Table 6.2 reports the number of independent observations $N$, the two collusion metrics $\varphi^E$, and the Friedman index for all experiments and treatments considered in this meta-analysis.[7] The following analysis is carried out in two steps: At first number effects are examined only within a single study (intra-study). Subsequently, tacit collusion in duopolies, triopolies, and quadropolies is compared across all studies (inter-study).

**RESULT 6.1.** *Within and across the surveyed oligopoly experiments, markets with two firms are significantly more prone to tacit collusion than markets with three as well as four firms, everything else being equal. However, no significant difference in the degree of tacit collusion can be found between three and four firms.*

With respect to the intra-study analysis, data on the level of independent observations could be obtained for five experiments.[8] Table 6.3 provides $p$ values from one-tailed non-parametric Mann-Whitney U tests of intra-study number effects on tacit collusion in these experiments. Following the hypothesis of a strictly monotonic relationship, the null hypothesis is that tacit collusion is always higher in a market with more firms. With

[6] For Orzen (2008), the Friedman index has to be averaged over all three successive phases in each treatment in order to gain a single index value.

[7] The original experimental data is either collected from tables in the respective study, downloaded from an online repository, or provided by the authors. One exception is Bosch-Domènech and Vriend (2003) for which the data is retrieved from figures.

[8] The author thanks Hans-Theo Normann and Henrik Orzen for providing the experimental data used in Huck et al. (2004b) and Orzen (2008), respectively.

TABLE 6.2: *Degrees of tacit collusion in economic laboratory experiments that vary the number of competing firms.*

| Study | Treatment | Periods[†] | $n$ | $N$ | $\varphi^{Nash}$ | $\varphi^{Walras}$ | *Friedman* |
|---|---|---|---|---|---|---|---|
| | | Bertrand (price) competition | | | | | |
| Fouraker and Siegel (1963) | Complete information | $[1,15] \in [1,15]$ | 2 | 17 | 0.412 | 0.412 | 0.766 |
| | | | 3 | 10 | 0.039 | 0.039 | 0.311 |
| | Incomplete information | $[1,15] \in [1,15]$ | 2 | 17 | 0.149 | 0.149 | 0.766 |
| | | | 3 | 11 | 0.019 | 0.019 | 0.311 |
| Dolbear et al. (1968) | Complete information | $[8,12] \in [1,15]$ | 2 | 18 | 0.300 | 0.500 | 1.250 |
| | | | 4 | 9 | −0.040 | 0.257 | 1.250 |
| Dufwenberg and Gneezy (2000) | 2/3/4 | $[1,10] \in [1,10]$ | 2 | 12 | 0.260 | 0.260 | 1.000 |
| | | | 3 | 8 | 0.067 | 0.067 | 0.497 |
| | | | 4 | 6 | 0.077 | 0.077 | 0.331 |
| Orzen (2008) | Fixed matching | $[1,90] \in [1,90]$ | 2 | 6 | 0.352 | 0.604 | 0.624 |
| | | | 4 | 6 | −0.025 | 0.381 | 0.206 |
| | Random matching | $[1,90] \in [1,90]$ | 2 | 6 | 0.113 | 0.462 | 0.624 |
| | | | 3 | 6 | −0.008 | 0.391 | 0.206 |
| Davis (2009) | 2np/3np/4np | $[1,220] \in [1,220]$ | 2 | 6 | 0.113 | 0.113 | 0.754 |
| | | | 3 | 6 | 0.006 | 0.006 | 0.376 |
| | | | 4 | 6 | 0.006 | 0.006 | 0.251 |
| Fonseca and Normann (2012) | NoTalk | $[1,29] \in [1,29]$ | 2 | 6 | 0.504 | 0.504 | 1.020 |
| | | | 4 | 6 | 0.060 | 0.060 | 0.338 |
| | | | 6 | 6 | 0.025 | 0.025 | 0.202 |
| | | | 8 | 6 | 0.011 | 0.011 | 0.145 |
| | | Cournot (quantity) competition | | | | | |
| Fouraker and Siegel (1963) | Complete information | $[1,22] \in [1,22]$ | 2 | 16 | −0.244 | 0.585 | 1.000 |
| | | | 3 | 11 | −0.266 | 0.367 | 0.750 |
| | Incomplete information | $[1,22] \in [1,22]$ | 2 | 16 | −0.114 | 0.629 | 1.000 |
| | | | 3 | 11 | −0.260 | 0.370 | 0.750 |
| Bosch-Domènech and Vriend (2003) | Easy | $[1,22] \in [1,22]$ | 2 | 9 | 0.296 | 0.765 | 0.889 |
| | | | 3 | 6 | −0.176 | 0.451 | 0.732 |
| | Hard | $[1,22] \in [1,22]$ | 2 | 9 | −0.159 | 0.614 | 0.889 |
| | | | 3 | 6 | −0.107 | 0.484 | 0.732 |
| | Hardest | $[1,22] \in [1,22]$ | 2 | 9 | −0.164 | 0.612 | 0.889 |
| | | | 3 | 6 | −0.491 | 0.304 | 0.732 |
| Huck et al. (2004b) | Unified frame | $[1,25] \in [1,25]$ | 2 | 6 | 0.403 | 0.801 | 0.889 |
| | | | 3 | 6 | 0.032 | 0.516 | 0.750 |
| | | | 4 | 6 | 0.065 | 0.439 | 0.640 |
| | | | 5 | 6 | −0.109 | 0.260 | 0.556 |
| Waichman et al. (2014) | DSNC/TSNC | $[1,17] \in [1,17]$ | 2 | 12 | −0.154 | 0.615 | 0.889 |
| | | | 3 | 13 | −0.265 | 0.367 | 0.750 |
| | DMNC/TMNC | $[1,17] \in [1,17]$ | 2 | 10 | −0.046 | 0.651 | 0.889 |
| | | | 3 | 11 | −0.062 | 0.469 | 0.750 |

[†] Periods used to compute the average degree of tacit collusion. If possible, data from all periods is used to maximize comparability.

TABLE 6.3: *Intra-study one-tailed Mann-Whitney U tests and associated p values.*

| Study | Treatment | $n$ | $\varphi^{Nash}$ | $\varphi^{Walras}$ |
|---|---|---|---|---|
| | Bertrand (price) competition | | | |
| Fouraker and Siegel (1963) | Complete information | 2 vs. 3 | $< 0.001$ | $< 0.001$ |
| | Incomplete information | 2 vs. 3 | 0.003 | 0.003 |
| Orzen (2008) | Fixed matching | 2 vs. 4 | 0.005 | 0.005 |
| | Random matching | 2 vs. 4 | 0.002 | 0.002 |
| Davis (2009) | 2np/3np/4np | 2 vs. 3 | 0.008 | 0.008 |
| | | 2 vs. 4 | 0.008 | 0.008 |
| | | 3 vs. 4 | 0.437 | 0.437 |
| | Cournot (quantity) competition | | | |
| Fouraker and Siegel (1963) | Complete information | 2 vs. 3 | 0.294 | 0.008 |
| | Incomplete information | 2 vs. 3 | 0.084 | $< 0.001$ |
| Huck et al. (2004b) | Unified frame | 2 vs. 3 | 0.019 | 0.004 |
| | | 2 vs. 4 | 0.019 | 0.002 |
| | | 3 vs. 4 | 0.261 | 0.261 |

the exception of the measure based on Nash predictions for Fouraker and Siegel's (1963) Cournot treatments, all test results indicate that tacit collusion is higher in duopolies than in triopolies (2 vs. 3) or quadropolies (2 vs. 4) at the 5% level of significance. However, triopolies are not found to be more prone to tacit collusion than quadropolies (3 vs. 4), neither under Bertrand competition nor under Cournot competition.

For inter-study comparisons the most comparable treatments between studies are selected in an effort to rule out any other explanations for differences other than the number of competitors. Thus, only treatments with complete and perfect information are considered for the following analysis.[9] Consequently, there are ten independent duopoly observations, seven independent triopoly observations, and six independent quadropoly observations. As there is only a single study for any $n > 4$ the statistical analysis is limited to markets with $n \in \{2,3,4\}$ firms. The Friedman index, which is suggested to assess the likelihood of tacit collusion, predicts poorly if correlated with $\varphi^{Nash}$ ($\rho = 0.213, p = 0.330$) but is positively and significantly correlated with $\varphi^{Walras}$ ($\rho = 0.593, p = 0.003$). In order to control for potential dependencies between treatments

[9]The following treatments reported in Table 6.2 are *not* considered in this step of the inter-study analysis: Incomplete information (Fouraker and Siegel, 1963), Random matching (Orzen, 2008), Hard and Hardest (Bosch-Domènech and Vriend, 2003), and DMNC/TMNC in which participants are managers instead of students (Waichman et al., 2014).

from the same study, i.e., different base levels of tacit collusion between experimental settings, the following three-level linear random-intercept model is estimated:

$$\begin{aligned}\varphi^E_{s,m,n} = \beta_0 &+ \xi_s + \zeta_m \\ &+ \beta_{Duopoly} \cdot Duopoly \\ &+ \beta_{Quadropoly} \cdot Quadropoly \\ &+ \beta_{Cournot} \cdot Cournot \\ &+ \epsilon_{s,m,n},\end{aligned}$$

where $\varphi^E_{s,m,n}$ is the average degree of tacit collusion $\varphi^E$ of markets with $n$ competitors under model $m \in \{Bertrand, Cournot\}$ in study $s$, $\zeta_m$ is the error component shared between observations of the same model in study $s$ (see Bertrand and Cournot treatments in Fouraker and Siegel, 1963), and $\xi_s$ is the error component shared between observations from the same study. The results, as portrayed in Table 6.4, confirm the insight of the above intra-study findings that there is significantly more tacit collusion in duopolies compared to triopolies and quadropolies. Furthermore, there is no significant difference in tacit collusion between triopolies and quadropolies. In particular, the degree of tacit collusion is, on average, 26 pp higher in duopolies than triopolies according to both collusion measures. On the contrary, the same does not hold for the comparison between markets with three and markets with four firms as triopolies are found to have, on average, an almost identical degree of tacit collusion than quadropolies. Also notice that the regression analysis replicates the finding by Suetens and Potters (2007) that *Bertrand colludes more than Cournot*—however, only if tacit collusion is based on Nash predictions. In contrast, when compared to Walrasian equilibrium, this effect is significant in the opposite direction. Thus, if a competitive market outcome where price equals marginal cost represents the benchmark for the degree of tacit collusion, *Cournot may collude more than Bertrand*.

All these results hold if tacit collusion metrics are averaged over all treatments from each study with the same competition model and two, three, or four firms, respectively (see Table B.14 in Appendix B.3 for results of the respective multilevel mixed-effects

TABLE 6.4: *Multilevel mixed-effects linear regressions of tacit collusion on number of competitors and competition model on the basis of most comparable treatments. Baseline: Triopoly & Bertrand competition.*

| Covariate | (1) $\varphi^{Nash}$ | (2) $\varphi^{Walras}$ |
|---|---|---|
| Duopoly | 0.259*** | 0.261*** |
| | (0.048) | (0.031) |
| Quadropoly | −0.020 | −0.003 |
| | (0.060) | (0.039) |
| Cournot | −0.227** | 0.263*** |
| | (0.088) | (0.050) |
| Constant | 0.056 | 0.156*** |
| | (0.067) | (0.049) |
| Studies | 9 | 9 |
| Models | 10 | 10 |
| Observations | 23 | 23 |

Baseline: Bertrand triopoly. Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

regressions). Furthermore, these findings can also be replicated by a meta-regression, a method vastly used in medical research (see, e.g., Higgins and Thompson, 2002), which takes into account the reliability of sample means from different studies by controlling for study-specific standard errors. The results of the meta-regressions are in line with the findings of the multilevel mixed-effects linear regressions presented in Table 6.4 and yield similiar effect sizes. See Appendix B.3 for a presentation and discussion of estimates.

Although the previous analyses control for different base levels of tacit collusion between experiments via multilevel mixed-effects regressions as well as for the reliability of sample means via meta-regressions, the data used in the previous regression models are unbalanced with regard to the different number of independent observations (treatments) for each number of competitors. Consequently, number effects are next investigated inter-study also via matched samples. By this means, a comparison of $n_1$ and $n_2$ competitors includes all studies that have conducted treatments with $n_1$ *and* $n_2$ competitors. Note that, therefore, the number of included studies varies between pairwise comparisons, e.g., when comparing two with four and two with three competitors.

TABLE 6.5: *Inter-study average degrees of tacit collusion and one-tailed matched-samples Wilcoxon signed-rank tests on the basis of most comparable treatments.*

| | Studies | $\varphi^{Nash}$ | $\varphi^{Walras}$ |
|---|---|---|---|
| *2 vs. 3* | | | |
| Duopoly | 7 | 0.155 | 0.507 |
| Triopoly | 7 | −0.081 | 0.259 |
| $p$ value | 7 | 0.009 | 0.009 |
| *2 vs. 4* | | | |
| Duopoly | 6 | 0.322 | 0.464 |
| Quadropoly | 6 | 0.024 | 0.203 |
| $p$ value | 6 | 0.014 | 0.014 |
| *3 vs. 4* | | | |
| Triopoly | 3 | 0.035 | 0.196 |
| Quadropoly | 3 | 0.049 | 0.174 |
| $p$ value | 3 | 0.946 | 0.500 |

Table 6.5 presents average degrees of tacit collusion and $p$ values based on one-tailed non-parametric Wilcoxon signed-rank tests. Again, the tested null hypothesis is that tacit collusion is higher in markets with less firms than in markets with more firms.

Test results show that tacit collusion is significantly higher in duopolies than in triopolies (2 vs. 3) and quadropolies (2 vs. 4), respectively. However, based on all experiments that run triopolies as well as quadropolies, the former is not more prone to tacit collusion than the latter (3 vs. 4). In fact and in stark contrast to the existence of a strictly monotonic relationship, tacit collusion may even be slightly higher in markets with four firms ($\varphi^{Nash} = 0.049$) than in markets with three firms ($\varphi^{Nash} = 0.035$) and this difference is almost significant at the 5% level ($N = 3, p = 0.054$). Again, results are similar if tacit collusion metrics are averaged over all treatments from each study with the same competition model and two, three, or four firms, respectively (see Table B.15 in Appendix B.3 for results of corresponding Wilcoxon signed-rank tests).

### 6.1.4 Discussion of the meta-analysis

Based on the survey of the extant literature, there is no pooled evidence that would support a general strictly monotonic relationship between the number of firms and the degree of tacit collusion in experimental oligopolies. Moreover, the studies that have examined number effects between three and four competitors within a single study likewise conclude that there is no significant difference between triopolies and quadropolies. For homogeneous Bertrand competition, both Dufwenberg and Gneezy (2000) and Davis (2009) find that experimental markets converge to the Nash equilibrium with three as well as with four competitors. For homogeneous Cournot competition, Huck et al. (2004b) find more competitive output levels with four compared to three firms in absolute terms, however, this effect is reversed if the collusion degree is measured relative to the Nash equilibrium. In summary, the results of the inter- and intra-study analyses are in line and suggest that the surveyed oligopoly experiments cannot support that markets with four firms exhibit ceteris paribus a lower degree of tacit collusion than markets with three firms. In conclusion, this contrasts the hypothesis of a strictly monotonic relationship between the number of competitors and the degree of tacit collusion in a market.

Although meta-analyses can provide valuable insight by evaluating robustness and external validity of systematic effects, they also have several limitations. First, the lack of control for all differences between studies considered in the same analysis limits the internal validity of meta-results per definitionem. Second, in this specific meta-analysis the number of independent observations of the pairwise comparisons is rather low, which raises concerns about statistical power. In particular, only three studies cover both triopoly and quadropoly treatments. Moreover, the individual studies themselves may lack statistical power to detect a difference between three and four competitors as the number of independent observations is often lower for markets with a larger number of competitors.[10] In addition, both experiments that examine number effects in the context of price competition in a single study employ a homogeneous Bertrand model, which arguably represents a special case with regard to number effects, because the theoretical prediction does in fact not change with the number of competitors. Last but foremost, none of the experiments in the meta-study employs treatments with all

[10]The three studies that examine triopolies and quadropolies (Dufwenberg and Gneezy, 2000; Huck et al., 2004b; Davis, 2009) each base their analysis on six independent quadropoly observations.

the relevant characteristics considered here, i.e., Bertrand and Cournot markets with two, three, and four firms.

## 6.2 Experiment with symmetric firms

Due to the lack of comprehensive evidence on a strictly monotonic relationship between the number of firms and the degree of tacit collusion in the extant experimental literature, two oligopoly experiments are conducted based on a design that exploits the duality between Bertrand and Cournot competition. First, this section considers the case of symmetric firms, which is also assumed in all of the oligopoly experiments surveyed in the meta-study. Next, the subsequent section considers asymmetry between firms.

### 6.2.1 Experimental design

Price competition à la Bertrand and quantity competition à la Cournot serve as good proxies for a large share of models on oligopoly competition. As homogeneous price competition is often deemed unrealistic and yields a discontinuous demand function, the model by Singh and Vives (1984) is considered that generalizes the Hotelling (1929) model to exploit the duality between price and quantity competition in differentiated goods. More precisely, the model's generalization to more than two firms (see Häckner, 2000) is used, which is described in further detail in Subsection 3.3.2. Appendix A.1 provides a thorough analysis of the general model with asymmetric firms and a formal derivation of the theoretical predictions, specifically, the Nash and the Walrasian equilibria as well as the joint profit maximizing outcome. For the assessment of symmetric firms, it is assumed that firms' goods are differentiated horizontally but are homogeneous in vertical quality and have identical demand elasticity.

Specifically, treatments are examined with Bertrand and Cournot competition in duopolies, triopolies, and quadropolies in a full-factorial design, resulting in a total of six treatments. In the following, these treatments are referred to with abbreviations such as B4 for the Bertrand quadropoly treatment. The model is parametrized with $\omega = 100$, $\lambda = 1$, and $\theta = \frac{2}{3}$. Consequently, $\Gamma = \frac{300}{2n+1}$, $\Lambda = \frac{6n-3}{2n+1}$, and $\Theta = \frac{6n-6}{2n+1}$. The theoretical benchmarks of the one-shot game for each treatment are reported in Table A.1 in Appendix A.1. As Nash prices, quantities, and profits do not coincide under Bertrand and Cournot competition and are additionally dependent on the number of competitors $n$, these values are not adequate to compare cooperative intentions, i.e., tacit collusion, across treatments. Thus, the same measure as for the meta-analysis is utilized, i.e., the degree of tacit collusion $\varphi^E$.

In a further effort to maximize comparability between treatments and to prevent any source for behavioral effects other than the treatment, input and output variables are scaled in the following way. The action space of prices in Bertrand treatments and quantities in Cournot treatments is equally set to $[0, 100]$ with a minimum increment of one and the JPM action at a price or quantity of 50. This ensures that the collusive action is not more or less behaviorally attractive across treatments and that the search costs of finding the collusive action are the same in all treatments. With a similar intention profits are scaled so that they would be equal in Nash equilibrium. Thereby, a subject playing the Nash equilibrium of the one-shot game—given that its competitors play Nash as well—would make identical profits in all treatments.[11] Altogether, this precludes confounding effects of the experimental design and parametrization.

Due to the normalization of input and output variables of the model, the different measures of the degree of tacit collusion have two desirable characteristics in the experiment. First, the Nash prediction-based degree $\varphi^{Nash}$ serves as a good predictor of relative differences in tacit collusion between treatments as Nash equilibria vary with the competition model as well as with the number of firms in the market. Second,

[11] Alternatively, profits may be standardized with respect to the collusive outcome. However, this would in turn lead to different Nash profits across treatments. Hence, firms would face diverse incentives to deviate from the theoretical Nash prediction.

TABLE 6.6: *Nash predictions $p^{Nash}/q^{Nash}$ as measured by the Walrasian-based degrees of tacit collusion $\varphi^{Walras}$.*

| | Bertrand | Cournot |
|---|---|---|
| Duopoly | 0.50 | 0.75 |
| Triopoly | 0.33 | 0.60 |
| Quadropoly | 0.25 | 0.50 |

the Walrasian-based measure of tacit collusion $\varphi^{Walras}$ assesses absolute differences to a uniform baseline, as the experiment is specifically designed to have a constant Walrasian equilibrium and collusive equilibrium across treatments. Due to the normalization of input variables, choosing a price or quantity of $p, q \in [0, 100]$ in the experiment directly translates to a Walrasian-based degree of tacit collusion of $2p\%$ in the Bertrand or $2(100 - q)\%$ in the Cournot treatments, respectively. Consequently, as the equilibrium price level is monotonically decreasing with the number of firms, the Walrasian prediction associated with each treatment's Nash equilibrium is also strictly monotonically decreasing as shown in Table 6.6. Therefore, if participants in the experiment behave in line with the Nash prediction and do not have an inexplicable preference towards a certain integer within the interval $[0, 100]$ or even choose prices and quantities randomly, the Walrasian-based tacit collusion measure is expected to decrease with the number of firms.

The consideration of the degree of tacit collusion based on the Walrasian equilibrium in the experiment is thus not only done for completeness, but also serves two additional purposes. First, the measure serves as a means to check whether subjects' behavior in the experiment are in line with decreasing Nash predictions for a larger number of firms. Although, Nash-consistent behavior is also indicated by $\varphi^{Nash} = 0$ across markets with a varying number of firms, this equality is difficult to verify empirically as a non-significant difference may also result from a lack of statistical power. Precisely in this case, the Walrasian collusion measure should indeed decrease with the number of firms, and should thus differ significantly between markets with a varying number of firms. Second, in the model consumer surplus as well as total welfare are monotonically decreasing in prices if goods are substitutes and hence, for regulatory authorities, the Walrasian equilibrium may constitute an additional relevant theoretical benchmark.

Perfect information is ensured in all treatments, i.e., subjects are provided with individual feedback about each competitor's price, quantity, and profit. In an effort to prevent that treatments evoke only short-term effects, the one-shot game is repeated 60 times. These repetitions are referred to as periods.

### 6.2.2 Procedures

The experiment is computerized with the *Java*-based experimental software *Brownie* (Müller et al., 2014). All sessions were run at the Karlsruhe Institute of Technology in Karlsruhe, Germany in October 2014 (duopoly and triopoly sessions), April 2015 (quadropoly sessions), and May 2016 (additional quadropoly sessions). Disregarding the first period, in which subjects familiarized themselves with the experimental software and decided on their initial price or quantity, the sessions took roughly 30 minutes on average. Note that there are no practice periods, neither with nor without interaction between subjects, and thus, no unobservable learning confounds occur. The matching of subjects is constant throughout a session (fixed partner matching). In total, 240 students of economic fields participated in the experiment. Subjects were recruited via the ORSEE platform (Greiner, 2015) and the hroot platform (Bock et al., 2014) and participated only in one of the treatments (between-subject design). The protocol for each session is identical to the protocol described in Subsection 3.3.2. The total length of a session from subjects' entering to leaving the lab was about one hour. The average payoff per subject was EUR 17.70.

### 6.2.3 Results

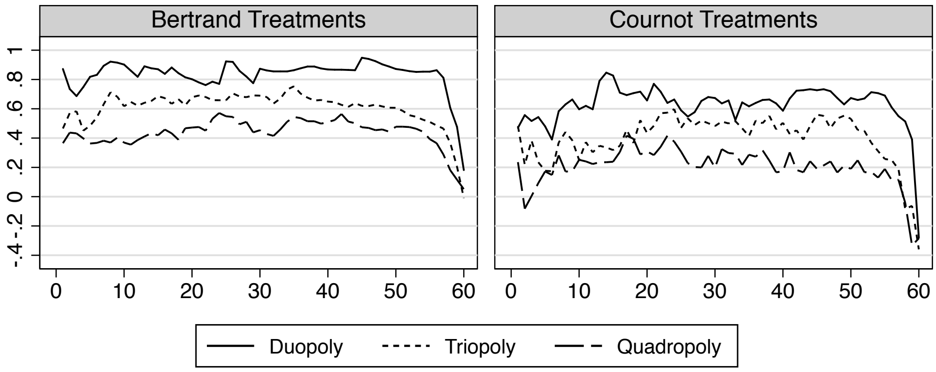
The experimental data amounts to 12 Bertrand and Cournot duopolies and triopolies, each, as well as 14 (16) Bertrand (Cournot) quadropolies. Before analyzing the exper-

TABLE 6.7: *Average degrees of tacit collusion across treatments.*

| Treatment | $N$ | $\varphi^{Nash}$ | $\varphi^{Walras}$ | *Friedman* |
|---|---|---|---|---|
| B2 | 12 | 0.832<br>(0.249) | 0.916<br>(0.124) | 0.750 |
| B3 | 12 | 0.605<br>(0.324) | 0.737<br>(0.216) | 0.556 |
| B4 | 16 | 0.436<br>(0.267) | 0.577<br>(0.200) | 0.438 |
| C2 | 12 | 0.627<br>(0.550) | 0.907<br>(0.138) | 0.936 |
| C3 | 12 | 0.397<br>(0.484) | 0.759<br>(0.193) | 0.831 |
| C4 | 14 | 0.206<br>(0.374) | 0.603<br>(0.187) | 0.750 |

Standard deviations in parentheses.

FIGURE 6.1: *Average degrees of tacit collusion $\varphi^{Nash}$ over periods across treatments.*




imental data longitudinally, Table 6.7 and Figure 6.1 provide an overview of experimental data[12] based on the level of independent cohorts over all 60 periods.[13] Similar to the previous meta-study, the Friedman index predicts the degree of tacit collusion poorly in terms of $\varphi^{Nash}$ ($\rho = 0.049, p = 0.670$), but is significantly correlated with $\varphi^{Walras}$ ($\rho = 0.409, p = 0.001$).

[12]Note that one duopoly in treatment C2 is exceptionally competitive. In particular, its average degree of tacit collusion based on Nash profits lies almost three standard deviations below the treatment mean. All results reported in the following hold if this outlier is dropped.

[13]Here, collusion degrees over all 60 periods as measured relative to the Nash equilibrium are displayed. Appendix B.3 depicts an analogous figure for collusion degrees measured relative to the Walrasian equilibrium.

For an in-depth analysis of firms' longitudinal behavior, a mixed-effects model is ran to control for different base levels of tacit collusion in cohorts via a random intercept as well as for different time dependencies due to learning via a random slope. Thus, the estimated model is

$$\begin{aligned}\varphi^{E}_{k,t} = \beta_0 &+ \xi_k \\ &+ \beta_{Duopoly} \cdot Duopoly \\ &+ \beta_{Quadropoly} \cdot Quadropoly \\ &+ \beta_{Cournot} \cdot Cournot \\ &+ (\beta_{Period} + \beta_{Period,k}) \cdot t \\ &+ \epsilon_{k,t},\end{aligned}$$

with $\varphi^{E}_{k,t}$ as the average degree of tacit collusion of all firms' prices or quantities in cohort $k$ in period $t$. Table 6.8 shows the estimated coefficients for both degrees of tacit collusion.[14] All results reported in the following with respect to prices or quantities hold also if the degree of tacit collusion is measured by transaction prices, i.e., prices weighted by the quantities sold.

**RESULT 6.2.** *In the experiment with symmetric firms, the degree of tacit collusion based on the Nash or the Walrasian equilibrium is significantly higher in markets with two firms than in markets with three as well as four firms, and significantly higher in markets with three firms than in markets with four firms, everything else being equal.*

In line with the meta-analysis, the duopolies show, on average, a statistically significant 20 pp higher degree of tacit collusion than triopolies based on Nash predictions. Moreover, and in contrast to the meta-analysis, quadropolies show a statistically significant 19 pp lower degree of tacit collusion than triopolies. The similar effect sizes of both coefficients indicate not only a strictly monotonic, but a linear number effect in the degree of tacit collusion. According to a Wald test, the equality of the absolute value

[14] Note that due to the dualism of the competition model used in the experiment, the degrees of tacit collusion measured by prices or quantities coincide.

TABLE 6.8: *Multilevel mixed-effects linear regressions of tacit collusion on number of competitors and competition model under competition between symmetric firms. Baseline: Symmetric Bertrand Triopoly (B3).*

| Covariate | (1) $\varphi^{Nash}$ | (2) $\varphi^{Walras}$ |
|---|---|---|
| Duopoly | 0.204** | 0.144*** |
| | (0.092) | (0.045) |
| Quadropoly | −0.193** | −0.167*** |
| | (0.087) | (0.043) |
| Cournot | −0.211*** | 0.008 |
| | (0.072) | (0.036) |
| Period | −0.001 | −0.001* |
| | (0.001) | (< 0.001) |
| Constant | 0.663*** | 0.776*** |
| | (0.075) | (0.037) |
| Cohorts | 78 | 78 |
| Observations | 4,680 | 4,680 |

Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

of treatment dummy coefficients cannot be rejected ($\chi^2(1) = 0.00, p = 0.946$). Measured relative to the Nash equilibrium, Bertrand competition colludes more than Cournot competition. In fact, the increase of 21 pp in the degree of tacit collusion is similar to the effect size found in the meta-study and also to the effect of an additional competitor in a market as measured above. Thus, with regard to number effects, the experiment replicates the findings of the meta-analysis with respect to duopolies and triopolies, but also identifies a significant effect between triopolies and quadropolies.

With respect to the Walrasian-based degree of tacit collusion measure the data shows a significant 14 pp (17 pp) increase (decrease) in duopolies (quadropolies) compared to triopolies. Hence, there is also a monotonically decreasing, approximately linear trend of the degree of tacit collusion as the number of firms in the market increases. These findings indicate that subjects do indeed react to differences in theoretical predictions. Moreover, there is a small yet significant negative time trend in the degree of tacit collusion if measured relative to the Walrasian Equilibrium.

In summary, the results attained from the experiment with symmetric firms provide support for the original conjecture of a strictly monotonic relationship between the number of competitors and the degree of tacit collusion. In fact, the measured effect sizes point to a linear trend with regard to the degree of tacit collusion relative to the Nash equilibrium.

## 6.3 Experiment with asymmetric firms

As tacit collusion has been attributed to be driven by symmetry of firms in the economic literature (Mason et al., 1992; Ivaldi et al., 2003), number effects in oligopolies may also interact with the (a)symmetry of firms. Therefore, two additional experimental treatments with asymmetric, i.e., vertically differentiated, firms are considered. Thereby, the experiment focusses on the comparison of triopolies and quadropolies, which clearly is the most interesting case in the light of the previous results.

Consideration of asymmetric firms also has a high practical relevance, particularly in the context of network industries, e.g., telecommunications and energy, which are still characterized by a dominance of the former (state-owned) monopolist. Therefore, a market structure with one incumbent and two or three entrants competing against each other is conceived in the following. In particular, this market structure resembles the regularities of many European mobile telecommunications markets, which are comprised of one large dominating and two or three smaller network operators, totaling at three or four cellular networks in each national market.

### 6.3.1 Experimental design and procedures

For means of comparability to the previous experimental treatments, the experimental design introduced in Subsection 6.2.1 is extended to allow for asymmetric firms. Asymmetry is implemented by establishing a single firm (i.e., the incumbent) with a higher quality good than the remaining—two or three—firms (i.e., the entrants). As consumers value quality, the incumbent's market share is higher than that of an entrant for identical prices. Equivalently, for equal market shares the incumbent may charge a higher price for its good than the entrants. In this vein, $\omega_k$ constitutes the reservation price of firm $k$'s consumers in the model and thus, may be interpreted as the quality of firm $k$'s product. Consequently, if the quality of one firm's product is higher than that of the other firms, i.e., $\omega_k > \omega_{-k}$, the former has higher market power that results in a higher equilibrium price, market share, and thus, profit. The extent of asymmetry in product quality can be expressed by a single parameter, $\Omega = \omega_{Incumbent} - \omega_{Entrant}$, which denotes the markup quality of the incumbent's good compared to the entrants' goods. See Appendix A.1 for the analysis of the model with horizontal as well as vertical differentiation.

Two additional asymmetry treatments—an asymmetric Bertrand triopoly (B3A) and an asymmetric Bertrand quadropoly (B4A)—are considered. The parametrization for entrants is the same as for firms in the symmetry treatments, i.e., $\omega_{Entrant} = 100$, $\lambda = 1$, and $\theta = \frac{2}{3}$. Motivated by common market shares in European telecommunications markets, $\Omega$ however is now greater than zero and chosen such that the incumbent's Nash equilibrium profit is 50% higher than an entrant's Nash equilibrium profit. Thus, the incumbent's market share with regard to its proportion of joint Nash equilibrium profits is $3/7 \approx 43\%$ in a triopoly and $1/3 \approx 33\%$ in a quadropoly. As market power is a relative rather than an absolute concept, holding the relative profit markup of the incumbent constant has two important advantages over alternative approaches, such as holding the incumbent's market share constant. First, this allows to normalize entrants' equilibrium profits such that they are the same as in the symmetry treatments (see below), which increases comparability across the symmetry and asymmetry treatments. Second, the additional relative market power of the incumbent compared to any single entrant is independent of the number of firms which increases comparability between asymmetric triopolies and quadropolies. For the two asymmetric Bertrand treatments a Nash equilibrium profit markup for the incumbent of 50% corresponds to $\Omega = 6.10$

in triopolies and $\Omega = 4.79$ in quadropolies. The theoretical predictions of the one-shot game for both asymmetry treatments are listed in Table A.2 in Appendix A.1.

In order to further ensure comparability, the same scaling and normalization as in the previous experiment is applied: First, the action space of the incumbent is scaled such that the JPM prices of all firms coincide at a price of 50 in an action space of $[0, 100]$. Second, profits are standardized such that an entrant would have the same Nash equilibrium gains as a firm in any of the symmetry treatments. Consequently, incentives to deviate from the theoretical Nash prediction are equal for entrants and symmetric firms in the previous experiment. The same scaling factor is applied to the entrants' profits as well as to the incumbent's profits so that the asymmetry in market power is not affected.

Except for an additional paragraph in the experimental instructions explaining how one of the firms differs from the others, the exact same experimental procedures are followed for the asymmetry treatments as previously for the symmetry treatments.[15] Again, the experiment was run at the Karlsruhe Institute of Technology in Karlsruhe, Germany, and participants were recruited via the ORSEE platform for sessions between June and August 2015 and via the hroot platform for sessions in May 2016. None of the 104 students of economic fields participating in one of the two asymmetry treatments had previously participated in one of the symmetry treatments. The participants' payoff averaged at EUR 19.82.

### 6.3.2 Results

Similar to the symmetry treatments, there are 12 independent asymmetric Bertrand triopolies and 17 independent asymmetric Bertrand quadropolies. Summary statistics for both new treatments are provided in Table 6.9. Means over cohorts are computed by averaging over all firms, i.e., the incumbent and each entrant are weighted equally. With

[15] As an example, the experimental instructions for the asymmetric Bertrand quadropoly treatment together with a screenshot of the experimental software are provided in Appendix C.3.

TABLE 6.9: *Average degrees of tacit collusion across asymmetry treatments.*

| Treatment | $N$ | $\varphi^{Nash}$ | $\varphi^{Walras}$ | *Friedman* | |
|---|---|---|---|---|---|
| | | | | Incumbent | Entrant |
| B3A | 12 | 0.332<br>(0.296) | 0.554<br>(0.197) | 0.792 | 0.444 |
| B4A | 17 | 0.217<br>(0.148) | 0.412<br>(0.111) | 0.619 | 0.379 |

Standard deviations in parentheses.

regard to the incumbent, the Friedman index is not significantly correlated with $\varphi^{Nash}$ ($\rho = 0.160, p = 0.408$), but significantly correlated with $\varphi^{Walras}$ ($\rho = 0.330, p = 0.081$). Regarding the entrants, the Friedman index—in line with the symmetry treatments—predicts $\varphi^{Nash}$ rather poorly ($\rho = 0.295, p = 0.120$) but has some explanatory power for $\varphi^{Walras}$ ($\rho = 0.453, p = 0.014$). Furthermore, the Friedman index predicts that the incumbent faces a higher incentive to tacitly collude—or, vice versa, that it has a lower incentive to deviate from a collusive agreement. Thus, according to the Friedman index, the entrants are supposed to be the drivers of competition. In the experimental sample, the incumbent indeed chooses, on average over both treatments, about 4 pp more collusive prices than the entrants if measured relative to the Walrasian equilibrium. This difference is significant according to a matched-samples Wilcoxon signed-rank test ($z = 2.87, p = 0.004$) and coincides with the disparity between the Nash predictions for the incumbent and entrants (see Table A.3 in Appendix A.1). In contrast, prices in terms of the degree of tacit collusion relative to the Nash equilibrium vary neither largely nor significantly between firms.

For an analysis of firms' behavior in the asymmetry treatments, a similar mixed-effects model as for the symmetry treatments is employed to control for different base levels of tacit collusion in cohorts via a random intercept as well as for different time dependencies due to learning via a random slope. Thus, the estimated model is specified as

$$\begin{aligned}\varphi^E_{k,t} = \beta_0 + \xi_k \\ + \beta_{Quadropoly} \cdot Quadropoly \\ + (\beta_{Period} + \beta_{Period,k}) \cdot t \\ + \epsilon_{k,t},\end{aligned}$$

with $\varphi^E_{k,t}$ as the average degree of tacit collusion of the incumbent's and the entrants' prices in cohort $k$ in period $t$. Table 6.10 provides estimated coefficients for both measures of the degree of tacit collusion.

**RESULT 6.3.** *In the experiment with asymmetric firms, the degree of tacit collusion based on the Nash or the Walrasian equilibrium is significantly higher in markets with three firms than in markets with four firms, everything else being equal.*

The Nash-based degree of tacit collusion is, on average, 21 pp higher in triopolies than in quadropolies. In line with the previous findings from the symmetry treatments, this difference is statistically significant and similar with respect to the effect size. Also consistent with the results under symmetry, the Walrasian-based degree of tacit collusion is significantly higher in markets with three firms than markets with four firms. Furthermore, a negative time trend of prices due to an end-game effect can be found for both measures. These results hold if only the entrants' degree of tacit collusion is used.[16]

In summary, the empirical results under asymmetry replicate the findings under symmetry and thus support the general conjecture of a strictly monotonic relationship. Whereas the relative effect on tacit collusion with regard to an additional competitor is similar across symmetric and asymmetric market structures, the absolute degree of tacit collusion for a market with a specific number of firms may differ, as a comparison of Tables 6.7 and 6.9 indicates.

[16]If only the incumbent's degree of tacit collusion is considered the difference between triopolies and quadropolies is statistically insignificant according to the specified mixed-effects model.

TABLE 6.10: *Multilevel mixed-effects linear regressions of tacit collusion on number of competitors under Bertrand competition between asymmetric firms. Baseline: Asymmetric Bertrand Triopoly (B3A).*

| Covariate | (1) $\varphi^{Nash}$ | (2) $\varphi^{Walras}$ |
|---|---|---|
| Quadropoly | $-0.213^{*}$ | $-0.203^{**}$ |
| | (0.120) | (0.081) |
| Period | $-0.004^{***}$ | $-0.002^{***}$ |
| | (0.001) | (0.001) |
| Constant | $0.497^{***}$ | $0.665^{***}$ |
| | (0.092) | (0.062) |
| Cohorts | 29 | 29 |
| Observations | 1,740 | 1,740 |

Standard errors in parentheses.
$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

While the detailed comparison of symmetry and asymmetry treatments is relegated to Appendix B.3, it is briefly highlighted that the experimental results indicate support for previous theoretical and empirical studies in their findings that symmetry seems to facilitate tacit collusion (see, e.g., Mason et al., 1992; Ivaldi et al., 2003; Fonseca and Normann, 2008). In particular with regard to quadropolies, asymmetry is a significant driver of competition, with the degree of tacit collusion relative to the Nash (Walrasian) equilibrium being 18 pp (13 pp) lower in asymmetric than symmetric markets with four firms. Put into context, the effect size of implementing asymmetry by increasing the market power of a single firm is comparable to the number effect on tacit collusion between markets with two and three firms as well as between markets with three and four firms.

In an effort to rule out social preferences—which may be viewed as an artifact of a laboratory setting—as a dominant motive for subjects' decisions to collude less under asymmetry, subjects' social value orientation is measured in an ex post questionnaire based on Murphy et al. (2011). A comparison of the social value orientation index reveals no differences between incumbents and entrants or subjects in triopolies and quadropolies (see Appendix B.3). In conclusion, these findings suggest that social orientations cannot explain why asymmetric firms collude less than symmetric firms.

## 6.4 Discussion

The question that motivates this chapter is rather blunt: *How many competitors are enough to ensure competition?* Evidently, it would be utterly unscientific to propose an answer to this question disregarding the particular characteristics and circumstances in a given market. But even if "case-by-case analysis implies that there is no 'magic number'" (Vande Walle and Wambach, 2014, p.10), the findings reported here point to systematic effects with regard to tacit collusion that should be given careful consideration by competition and regulatory authorities when assessing the question of how to achieve and safeguard effective competition in a market.

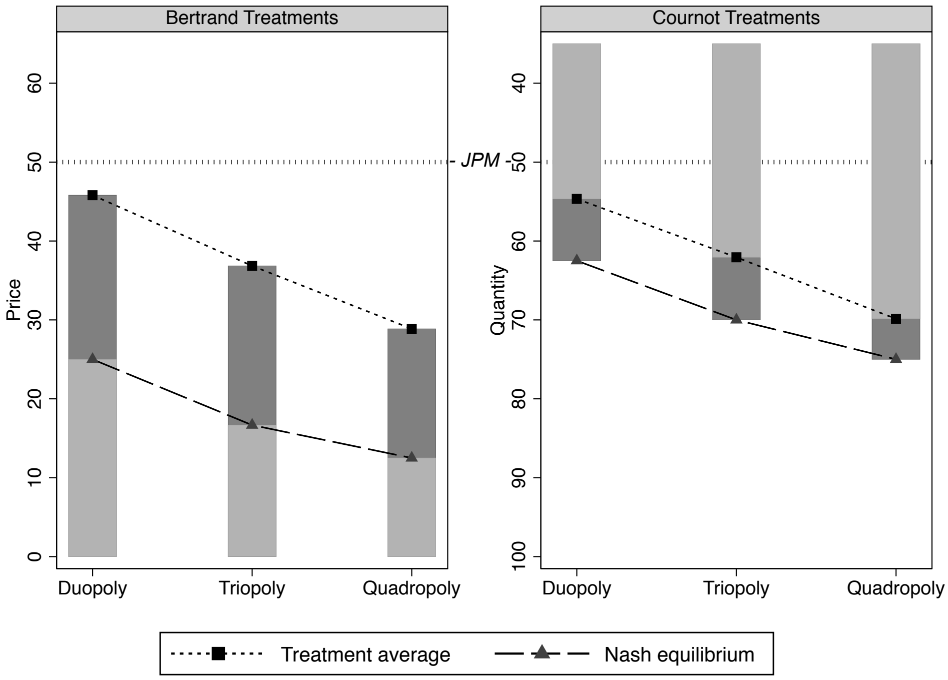
To this end, the three presented studies provide comprehensive evidence based on either existing or new oligopoly experiments, considering a different number of firms (two vs. three vs. four firms), different modes of competition (price vs. quantity competition) and different degrees of market power (symmetric vs. asymmetric). First, the meta-study on the extant literature studying number effects in experimental oligopolies provides robust empirical support that tacit collusion is significantly higher in markets with two firms compared to markets with three firms as well as to markets with four firms. In contrast, neither intra-study nor inter-study evidence confirms a significant effect between markets with three firms and markets with four firms. Thus, the extant literature does not provide any evidence for the original conjecture of a strictly monotonic relationship between the number of competitors and the degree of tacit collusion under Bertrand or Cournot competition.

However, there are several limitations to the meta-analysis itself as well as the individual studies that compare markets with three and four firms. First, the data collected from experimental studies for the meta-study is heterogeneous in quality, i.e., it is either obtained from the authors directly, from tables in the article, or even retrieved from figures. As a consequence, the granularity of the data varies across studies. Data on the level of independent observations from sessions is only provided for half of the studies considered here and hence, intra-study treatment differences are not replicable nor testable for the remaining studies. Second, the number of experimental studies surveyed in the meta-analysis is rather low, especially with regard to effects between triopolies and quadropolies, and thus the results are based on a small number of observations. Moreover, within the individual studies, the number of independent observations—in particular the number of independent quadropoly observations—is also rather low. In consequence, the meta-study as well as individual studies may simply lack the statistical power to detect a potential number effect between triopolies and quadropolies (cf. List et al., 2011; Bellemare et al., 2014).

Therefore, two experiments are conducted that further test the relative competitiveness in triopolies and quadropolies based on a dataset with a considerably larger number of independent observations and an experimental design that exploits the duality between differentiated Bertrand and Cournot competition. As a result, a significant effect between markets with three firms and markets with four firms is found for both symmetric and asymmetric distributions of market power. Remarkably, the effect size of a 20 pp lower degree of tacit collusion is very similar from *four to three* firms as well as from *three to two* firms across symmetric and asymmetric treatments. This points not only to a strictly monotonic trend, but to a linear relationship between the number of firms and the degree of tacit collusion measured relative to the Nash equilibrium. Figure 6.2 summarizes these findings and depicts the number effect in prices/quantities across symmetric Bertrand and Cournot treatments.

Furthermore, the results both confirm and shed new light on previous insights. First, the results indicate that already the judgment of the competitiveness of a certain mode of competition (price vs. quantity competition) depends on the point of reference (Nash vs. Walrasian equilibrium). In particular, Suetens and Potters (2007) suggest that Bertrand colludes more than Cournot. However, as the empirical analysis reveals, this holds only with respect to Nash equilibria. Instead, if tacit collusion is measured with regard to Walrasian equilibrium, the opposite may hold. This finding of the meta-study is in line with the stronger competition predicted by the Nash equilibrium under Bertrand competition than under Cournot competition. Second, the findings are in line

FIGURE 6.2: *Number effects across symmetric treatments.*




with the notion that tacit collusion is more likely to emerge among symmetric rather than asymmetric firms.

Whereas the conducted experiments address the limitations of the meta-study, they are at the same time limited to the specific parametrization used. This applies to both the specific demand parameters as well as to the way in which prices and profits are normalized and scaled across treatments in order to maximize comparability. Also the asymmetry between competitors may be parametrized in various ways, e.g., based on differences in Nash profits or based on absolute differences in product quality. Although there is considerable variation in parametrization across the studies included in the meta-analysis, it cannot be ruled out that the results of the conducted experimental studies are to some degree affected by the specific parametrization used.

As a further limitation of all studies it is noted that competition in experimental Bertrand and Cournot oligopolies is merely considered with exogenously symmetric or asymmetric firms but not in the context of endogenous merger formation. Furthermore, neither the experiments considered in the meta-analysis nor the conducted experiments allow for investments in order to increase the market size, which arguably plays an important role in most industries that are characterized by an oligopolistic market structure. With regard to a risk-averse regulator not only averages of market outcomes may be of interest. Instead, authorities may also take into account the effect, which the number of firms and regulatory institutions have on the variance of the expected competitive intensity, in order to minimize the possibility of tacit collusion. However, based on the samples in the meta-analysis as well as both oligopoly experiments, there are no significant differences in this regard.

These limitations give rise to future research on number effects in oligopolies. In particular, the variety of asymmetric market settings offers opportunities for scenario-specific investigations of competitive effects. For instance, a decrease in the number of competitors in a market, e.g., through a merger, is also likely to affect the horizontal and vertical differentiation of firms' products. In this vein, a merger may introduce asymmetry in the market power of the remaining firms and thus not only relax competition due to the decrease in the number of firms but also foster competition. Therefore, further experimental studies in the spirit of current replication efforts (see, e.g., Camerer et al., 2016) are desired to test the robustness and generality of the presented findings (see Chapter 8 for a more elaborate discussion on this issue).

# Chapter 7

# Voluntary Open Access in Digital Services Markets

THE Internet as an online platform ecosystem now encompasses a diverse set of web pages, mobile apps and services, shopping and product comparison sites, as well as content and media platforms. The rapid expansion of this ecosystem and its user base is spurred by the entry of new platforms and increased specialization of individual outlets. At the same time, a small number of general-purpose platforms has emerged, especially social networks. These platforms are now often characterized as the *gateways to the Internet* (Arakali, 2015; Barnett, 2010) as they are used by the vast majority of Internet users and often serve as a starting point for their online activities. The most prominent example, Facebook, served 1.59 billion monthly active users worldwide at the end of 2015 (Facebook, 2016) and a 74% share of US online adults in 2014 (Pew Research Center, 2016). Next to the sheer amount of user data, these platforms—and Facebook in particular—are in the possession of unique personal data as its social and personalized services naturally require accurate and extensive information input from its users.

Expansion and specialization at the edges on the one hand, together with increased concentration at the core on the other hand, have created a situation in today's online

This chapter is based on joint work with Jan Krämer and Michael Wohlfarth (Krämer et al., 2016).

platform ecosystem where *user data* and *usage data* are collected and stored by different entities. In consequence, there emerges a rationale for data sharing between online content providers (CPs)—and even competitors—to combine data sources in order to enhance knowledge about users and potential customers. *Targeting* of consumers based on a superior data set is viewed as a major competitive advantage in these markets, particularly in the context of online advertising. Next to purchasing usage data ex post in the form of collected tracking data through specialized intermediaries or markets (cf. Montes et al., 2015), CPs may try to directly access and share users' data across platform boundaries. So-called *social logins* (Gafni and Nissim, 2014; Janrain, 2014), which allow users to authenticate with third-party CPs through their social network account have been established as one of the most popular instruments to share user and usage information among online outlets. The most popular social login[1], *Log in with Facebook*[2], e.g., allows websites and mobile apps to access users' public profile including demographic data, email address and friends. Moreover, access to extended profile properties such as the history of users' likes or recorded web activities may be requested from the user.[3] In return, Facebook obtains comprehensive data on users' activities at the third-party outlet through the programming interfaces of the login service. In fact, Facebook states that it "can analyze [a third-party's] app, website, content, and data for any purpose, including commercial" in its Platform Policy.[4]

Whereas ex post data sale and purchase transactions are frequently conducted without the knowledge of the data subject concerned, consumers choose the social login service actively and voluntarily. Such user control has been found to be vital for successful marketing campaigns in the context of social media (Fournier and Avery, 2011; Tucker, 2014). In fact, the widespread popularity of social logins indicates that reduced transaction costs as well as enhanced personalization and customization provide real added value to users (see Acquisti and Varian, 2005, for a related scenario where personalization alters consumers decisions in the context of price discrimination). Already in 2010,

[1] According to LoginRadius (2015) 97% of websites that offer a social login employ Facebook's login.
[2] See `https://developers.facebook.com/docs/facebook-login`. Accessed March 14, 2016.
[3] For a comprehensive list of accessible properties see `https://developers.facebook.com/docs/facebook-login/permissions`. Accessed March 14, 2016.
[4] See `https://developers.facebook.com/policy`. Accessed March 14, 2016.

two years after the launch of the service, Facebook stated that 250 million consumers and two million third-party websites used its social login and that the installed base was growing by 10,000 sites per day (Grove, 2010). The current installed base is estimated at almost 10 million web sites (SimilarTech, 2016). According to Janrain (2014) 51% (88%) of consumers have used (encountered) a social login at least once and more than half of the users (64%) "are more likely to return to a website that remembers them without a username and password". In this vein, increased user engagement and interaction are often quoted as main reasons for outlets' decision to adopt a social login (see, e.g., Gigya, 2015). However, the emergence of social logins as universal authentication and authorization services has not been without criticism. Next to privacy and security concerns and users' inability to internalize potential long-term disadvantages (Breuer et al., 2015; Kontaxis et al., 2012), strategic threats due to dependency on and exploitation by a dominant undertaking (Feingold, 2013) as well as legal risks (Van Der Sype and Seigneur, 2014) have been cited as major issues for CPs who decide to adopt a social login.

Despite the practical relevance, online CPs' incentives to offer direct access to user information or to share usage data by means of a social login together with the ensuing effects on competition have not yet been addressed in depth by the academic literature. This chapter scrutinizes outlets' strategic decisions whether to offer and/or adopt a social login, identifies the feasible market outcomes and highlights the implications for the involved decision makers. The incentives and fundamental trade-offs that drive adoption decisions and impact the profitability of CPs are examined based on a stylized model of horizontal competition between special-intererst CPs (who may adopt the login), and advertising competition between special-interest CPs and the general-interest CP (who may offer the login). Whereas there are situations where all parties are mutually better off, it is demonstrated that special-interest CPs may implement a social login even in cases where this decision ultimately makes them worse off, i.e., they may find themselves in a prisoner's dilemma-like situation. On the contrary, there may also arise situations where the general-interest CP does not offer the social login although it would be beneficial to consumers. This may provide a rationale for potential policy interventions in the form of Open Access based on no-discrimination considerations, which have traditionally been debated at the network layer (see Chapter 2), but may be extended to the platform layer as discussed by Graef et al. (2015) and Easley et al. (2015). This could in consequence restrict services provider's discretion with regard to discriminatory practices.

The remainder of this chapter is structured as follows: Section 7.1 surveys related literature strands on single sign-on systems, access to user data and user privacy, online advertising and targeting, which inform the model framework presented in Section 7.2. The model is analyzed and the feasible market outcomes are presented in Section 7.3. Section 7.4 discusses policy questions together with possible extensions and limitations.

## 7.1 Related literature

Although social login mechanisms have so far been explicitly addressed either by scholars concerned with usability of services and user acceptance (Egelman, 2013; Gafni and Nissim, 2014), from a technical perspective (Breuer et al., 2015; Kontaxis et al., 2012), or from a legal point of view (Van Der Sype and Seigneur, 2014), there are several related strands of literature in the domains of economics, management and marketing, as well as information systems, which will be discussed in the following.

One strand of studies explores the factors that affect consumers' decision to use a social login rather than a website's own registration service. For example, Kontaxis et al. (2012, p.321) point to an additional "social dimension to the browsing experience" due to users' ability to share, rate and interact with content. These features require the sharing of user and usage data between the respective social network and the content provider. Based on an exploratory survey, Gafni and Nissim (2014) identify familiarity and convenience as factors that positively affect users' readiness to opt for a social login in a world in which Internet users face an increasing number of websites that require authentication. In such cases, social logins avoid the need for multiple (different) username and password combinations, evade repetitive registration processes and minimize the effort to update and maintain accurate information in the case authentication properties change. In a laboratory experiment, Egelman (2013) examines convenience benefits of the Facebook Login relative to perceived privacy costs and finds that for the majority of subjects the former outweighs the latter even if this requires the disclosure of extensive personal information and although subjects are well-aware of the scope of collected data.

The technical literature views social login services (Ko et al., 2010) in the history of (enterprise) *single sign-on systems* (SSOs), i.e., systems that allow for centralized and federated identity management across remote and distributed resources (Pashalidis and Mitchell, 2003). Next to the design and implementation of authentication protocol standards, e.g., *OAuth* (Sun and Beznosov, 2012; Chen et al., 2014), studies have been concerned with the security of data transmission (Wang et al., 2012) and users' control over their personal data in different services contexts (Dey and Weis, 2010; Kontaxis et al., 2012). In essence, these studies suggest that social logins reduce users' transaction costs in a distributed (web) context, if technical systems are designed and implemented securely and with regard to users' privacy concerns. However, Sun et al. (2010) also note that many SSOs, in particular open source systems, failed due to a lack of adoption incentives for involved platforms and content providers.

Additionally, social logins introduce new business opportunities and thus adoption incentives through the access to external data sources and potential sharing agreements among competitors. With regard to such *voluntary access* relationships among competitors, well-known economic trade-offs for the involved transaction parties arise (Boudreau, 2010; Mantena and Saha, 2012; West, 2003). In general, a firm needs to consider whether additional access revenues (e.g., wholesale revenues in vertical markets, cf. Ordover and Shaffer, 2007) outweigh the business stealing effect (Mankiw, 1986), due to competitors' access to the firm's exclusive resources. Moreover, wholesale access has been found to soften competition in downstream markets (Bourreau et al., 2011), whereas with regard to price discrimination a common data pool may intensify competition (Fudenberg et al., 2000; Montes et al., 2015). Thus the interplay between data sharing and competitive intensity is a priori unclear.

Incentives to collect data were scrutinized with regard to firms' ability to price discriminate based on historic usage data when consumers react to such practices (see Fudenberg and Villas-Boas, 2007, 2012, for summaries of behavior-based price discrimination in digital markets). More specifically, Acquisti and Varian (2005) show that personalization of services which increases consumers' valuation over time of use may be critical to make price discrimination profitable if consumers act strategically. Access to users' personal data may invoke a range of *privacy* issues that have been examined by a growing strand of theoretical and empirical literature (see Acquisti et al., 2016, for an extensive survey). With regard to social logins, authors have criticized inter alia the loss of anonymity, revelation of social information, loss of traceability in cases of a data breach, propagation of advertisements, and disclosure of user credentials as potential threats to users' privacy (Kontaxis et al., 2012). However, the fact that users deliberately decide to use the social login opposed to alternative registration options suggests that the positive effect on users' valuation outweighs potential privacy concerns (Egelman, 2013).

Over and beyond the ability to offer personalized services and prices, data collection and analysis is driven by the desire to improve the display of *online advertising* and to better match advertising to users' preferences by the means of *targeting*. Evans (2008) provides an overview of online advertising markets and characterizes key features that differentiate them from traditional media markets (Anderson and Coate, 2005). Bergemann and Bonatti (2011) show that on the one hand targeting benefits consumers through improved matching between consumers' preferences and advertised products, but on the other hand, targeting increases market concentration in the advertising industry.

Online advertising allows for a much more diverse set of pricing models and performance metrics than for offline advertising (Asdemir et al., 2012): Consumers' response to online advertising may either be measured based on *click-throughs*, i.e., the immediate engagement with the advertisement, or based on *view-throughs*, i.e., the more comprehensive long-term effect on consumers' purchase decision (Bleier and Eisenbeiss, 2015). Next to potential brand building effects (Yoo, 2009) and long-term impact on consumers' decision (Drèze and Hussherr, 2003; Manchanda et al., 2006; Lewis and Reiley, 2014), which are neglected by click-based or action-based measures, the academic literature has identified moral hazard as a potential impediment to the adoption of pricing models associated with pure click-through measures (Animesh et al., 2010; Asdemir et al., 2012; Liu and Viswanathan, 2014) or action-based measures (Hu et al., 2015). View-through (which includes click-through) is therefore commonly considered as the relevant performance measure in display advertising markets (Hamman and Plomion, 2013) and especially by advertisers in social networks. According to market research (Ross, 2015) more than 60% of total advertising budget spent at Facebook is allocated via *optimized CPM (oCPM)*, a metric where advertisers are billed on the basis of impressions, while Facebook optimizes bidding for the effective cost per impression according to advertisers' preferred mix of user interaction (actions, reach, clicks or social impression).[5] With close to 24% of total revenues in 2014 (eMarketer, 2015) and a third of total display impressions to US Internet users in 2011 (comScore, 2011), Facebook has become the clear market leader in display advertising and its share is estimated to grow further over the coming years (Marshall, 2015).

Through the social login, Facebook and other social networks may be able to drastically improve their ability to display targeted advertising and thus to increase view-through. According to Iyer et al. (2005) ubiquitous data gathering allows firms to gain "much better information on consumers, their preferences and their media habits" (p.461). Moreover, the advent of new media in combination with fragmentation of traditional media allows firms to differentiate and delineate between target segments. In particular, Iyer et al. show that targeting increases advertisers profits by reducing *wasted impressions* to consumers who are not interested in an advertiser's product. In economic theory,

[5]Further information is provided by Facebook's documentation of pricing models and advertising objectives: `https://www.facebook.com/business/help/355670007911605`. Accessed March 14, 2016.

consumers benefit from improved targeting of advertising, because the displayed ads are perceived as more relevant to their interest and therefore also more informative (Butters, 1977; Anand and Shachar, 2009). This in turn leads to increased user engagement for respective advertisers. Although survey-based research also identifies potential adverse effects due to better informed advertising (Turow et al., 2009), empirical studies generally support the hypothesis that data collection and analysis increases the effectiveness of displayed advertisements by the means of targeting (Braun and Moe, 2013; Goldfarb and Tucker, 2011a,b; Urban et al., 2014) and personalization (Ansari and Mela, 2003; Bleier and Eisenbeiss, 2015; Tucker, 2014).[6] In particular, Goldfarb and Tucker (2011a) find that targeted ads, which, e.g., would match the content of the visited website, exhibit a significantly higher effectiveness than conventional non-targeted ads. Moreover, in a study of advertising effectiveness on Facebook, Tucker (2014) finds that personalization of ad impressions in addition to targeting further increases the likelihood that users click on displayed ads if consumers maintain (perceived) control over their privacy. With regard to retargeting effectiveness, Lambrecht and Tucker (2013) and Bleier and Eisenbeiss (2015) show that advertisers need to be accurately informed about the current status of consumers' purchasing decision process. This further emphasizes the necessity for a firm's global view on consumers' activities over and beyond its own platform.

In the following, a game-theoretic model is developed that offers a microfoundation and characterization on how social logins affect the competition between CPs for users, as well as the competition between CPs and the social network for advertising revenues. Research gaps of the extant literature are addressed by explicitly considering the effects of data access and information sharing among competitors on CP's ability to attract users as well as its ability to generate advertising revenues. Moreover, factors that impact CPs decision to offer access to user data and/or usage data are examined. More specifically, it is shown that a higher competitive intensity between special-interest CPs

[6]See Tucker (2012) for a discussion of adverse effects on advertising effectiveness if user perceive data collection as excessive. However, these issues may be resolved by (perceived) user control over disclosure of their personal data as shown by Tucker (2014).

makes information sharing with a general-interest CP more likely even if this is ultimately detrimental to the special-interest CPs.

## 7.2 A model of coopetition in online advertising markets

Before providing the details of the model, the basic competitive setting is outlined.

### 7.2.1 Competitive setting

The considered online advertising ecosystem includes two competing special-interest content providers (CP $s$, $s \in \{A, B\}$), one general-interest content provider (CP $G$) and one advertiser ($Z$). The special-interest CPs may be thought of as specialized web sites that offer a narrow range of content in the same domain of interest (e.g., celebrity news *or* financial news), whereas the general-interest CP offers a much broader range of complementary content (e.g., a general news site). In the context of this chapter and the preceding motivation it will be convenient to think of CP $G$ as a social network provider (e.g., Facebook, Twitter, LinkedIn or GooglePlus), although the insights of the model are not restricted to this scenario. The important aspect of the model is that the special-interest CPs operate in the same domain and are thus competing directly for users, whereas the general-interest CP is already used by all Internet users under consideration. This captures the relevant competitive dynamics of the Internet, where, on the one hand, users split their attention between a general-interest site (e.g., Facebook) and a particular special-interest site, but, on the other hand, choose to pay attention to only one of the two comparable special-interest sites (e.g., they visit either hellomagazine.com or ok.co.uk, but not both). In other words, whereas users multi-home between CP $s$ and CP $G$, they single-home between CP $A$ and CP $B$.

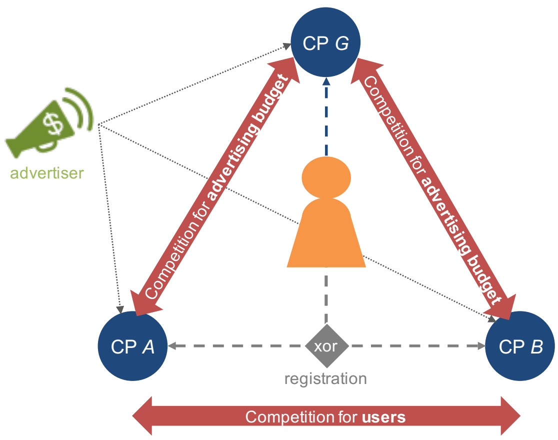
Furthermore, it is assumed that all CPs offer their content free of charge to Internet users and derive revenues by charging a price, $p$, for showing display advertisements on their sites. To date, this is the prevalent business model on the Internet (cf. Dou, 2004; Evans, 2009; Anderson, 2012) and consequently, this is the dominant modelling assumption in the related literature (see, e.g., Athey et al. (2014); Choi and Kim (2010); Kourandi et al. (2015)).[7] To fix ideas, it is assumed that CPs offer advertisement space based on pricing per impression (i.e., they adopt a cost-per-mille (CPM) model). Although, there exist also other means to sell advertisement space, in particular based on pricing per click (cost-per-click (CPC) model) or per transaction on the advertiser's site (cost-per-action (CPA) model), CPM is still widely adopted by large CPs (e.g., Facebook, Google Ad Sense) and consequently, this is the standard assumption used in the context of display advertisements markets (see, e.g., Anderson and De Palma (2013); Johnson (2013); Reisinger (2012)).[8] In order to focus on the competition between CPs, it is further assumed that there is a single advertiser, $Z$, that wishes to buy advertisement space for a special-interest ad (in the same domain as the special-interest CPs) at any one of the CPs. As will be described in detail subsequently, CPs differ in their targeting ability and, due to competition and split attention between CPs, each CP reaches a different subset of the users at any given point in time. Depending on a CP's ad pricing relative to how many view-throughs can be achieved at this CP, the advertiser will choose at which subset of the CPs to advertise in order to maximize its profit. Thus, it is important to see that, although the general-interest CP is not in direct competition for users with any of the special-interest CPs, it is still in competition with them for users' attention to

[7]However, this assumption is mainly made for convenience and clarity of the model, because it would only be required that CPs derive a significant portion of their total revenues from advertising. Other revenue streams (e.g., from transaction fees or subscriptions) are not considered here, because they are not directly relevant to the analysis of the competitive dynamics of the online advertising market, which is the focus of this analysis.

[8]Moreover, as will be seen later, the CPM model allows for the formulation of an intuitive microfoundation of how advertisement prices are formed and affected by the competition between CPs. The corresponding microfoundation would be more complicated and hence, less intuitive under a CPC model, without providing additional insights. The results remain qualitatively unaffected as long as a CP's advertisement price increases with the attractiveness of that CP to users (which is especially the case for enhanced targeting, see Athey and Gans, 2010). For a more detailed analysis of the trade off between the CPC and CPM model, see Asdemir et al. (2012).

ad impressions. This basic competitive set-up of the model is summarized in Figure 7.1.

FIGURE 7.1: *The competitive setting of the model: Each user chooses exactly one of the two special-interest CPs (single-homing) and splits attention between the special-interest CP and the general-interest CP (multi-homing). All CPs are ad-financed and receive advertisement revenues according to their relative ability to reach ad-relevant users.*




### 7.2.2 Details of the model

In the following, a more detailed description of the building blocks of the model, the strategic variables of each of the entities involved, as well as the timing of actions will be provided.

**Internet users** There is a unit mass of heterogeneous Internet users that have a natural preference for one of the two special-interest CPs. Users' preference for the CPs is denoted by $x$ and assumed to be uniformly distributed between zero and one (Hotelling, 1929). The two special-interest CPs are horizontally differentiated and located at either end of the users' preference spectrum, i.e., CP $A$ at $x = 0$ and CP $B$ at $x = 1$. Thus, a type $x$ consumer derives utility of $U_A(x) = u_A - \tau x$ or $U_B(x) = u_B - \tau(1 - x)$, when he consumes the content of CP $A$ or CP $B$, respectively. Thereby, $u_s$ denotes the base utility that is derived from the viewing experience and usability of the site (e.g., the quality of the content or the hassle of the login procedure), and $\tau$ is the degree of competition between the two special-interest CPs. When $\tau$ is large, the users' innate preference for the CPs becomes more important, such that competition on the basis of $u_s$ becomes weaker. Users will visit only the special-interest CP which gives him the highest utility. The respective user demand for CP $s$ is denoted by $D_s$. Furthermore, it is assumed that $u_s$ is large enough, such that the market is fully covered, i.e., at any time $D_A + D_B = 1$.

Besides one of the special-interest CPs, the users will also visit the general-interest CP. In order to model how users split attention between the two considered CPs, it is assumed that there are two time periods, indexed by $t = 1,2$. In each time period, a user visits the special-interest CP with probability $\delta$ and the general-interest CP with probability $1 - \delta$. Thus, $\delta$ and $1 - \delta$ are referred to as the screen attention probability of CP $s$ and CP $G$, respectively. Consequently, in each time period $t$, a special-interest CP $s$ expects to be viewed by a total of $D_{s,t} = D_s \delta$ users, whereas the general-interest CP $G$ expects a total of $D_{G,t} = (D_{A,t} + D_{B,t})(1 - \delta) = 1 - \delta$ viewers per time period.

**Content providers** All content providers $k \in \{A, B, G\}$ receive revenues from selling advertisement space to the advertiser. In principle, each CP demands a price for displaying the ad on its site in both time periods. In order to focus on the relevant aspects of the model the costs of providing content of each CP are normalized to zero and it is further assumed that advertisements can be displayed at zero marginal costs. Moreover, it is important to highlight that the special-interest CP $s$ is only in competition with CP $G$ for views, because users single-home between special-interest CPs. Thus, prices will depend on the submass of consumers, $D_s, s = A, B$ that is considered. Therefore, CP $s$'s price is denoted by $p_s$ and CP $G$'s price for the submarket $D_s$ is denoted by $p_{G(s)}$.

Consequently, the profit of CP $s$ is $\Pi_s = p_s$, whereas the profit of CP $G$ is $\Pi_G = \sum_{s=A,B} p_{G(s)}$. While a CP seeks to maximize its profit from advertising, $p$ will depend on the CPs' ability to reach ad-relevant users, which is influenced by two factors: (i) the number of a CP's viewers in time period t, which again depends on competition and screen attention, and (ii) its ad targeting rate $\alpha_k \leq 1$. A CP's targeting rate denotes which fraction of the viewers that actually see the ad belong to the advertiser's target group. More specifically, the targeting rate describes view-through, i.e., how well a CP can transform views into relevant advertising impressions.

In this context, it should be emphasized that the model is set up to analyze the economic effects that arise in competition for the advertising budget of a particular advertiser targeting a specific audience. Thus, attention is restricted to the subset of the online advertisement ecosystem that is relevant for this advertiser, comprised of special-interest websites (targeted at roughly the same audience as the advertiser) and general-interest websites. Evidently the special-interest CPs are considered by a much smaller number of advertisers (which is approximated by a single advertiser here) than the general-interest CP, who will therefore display a larger variety of ads. The revenue streams that may arise for the general-interest CP from these other advertisers are not explicitly modeled, because they are not relevant for the economic effects that arise in any given advertisement submarket, which is considered here.

CP $G$ may choose to offer CP $s$ a *social login*. If CP $s$ chooses to adopt the social login feature on its site, the two CPs implicitly agree to cooperate by means of sharing information about their users. Formally this has two implications:
First, it is assumed that CP $s$'s base utility, $u_s$ increases by $\theta \geq 0$. This can be motivated by a better user experience at CP $s$, e.g., because the same credentials can be used at both CPs, which limits password fatigue and lowers transaction costs of registration, or because information sharing enables better personalization of content and better integration of the services of both CPs. Of course, there may also be countervailing effects

on the users' experience, in particular due to concerns of privacy or a single point of failure.[9] However, it is assumed that the overall users' experience is better with the social login. More formally:

$$u_s = \begin{cases} u_s^b, & \text{if CP } s \text{ does not use the social login} \\ u_s^l = u_s^b + \theta & \text{if CP } s \text{ uses the social login,} \end{cases}$$

whereby the superscript $l$ denotes the case where the login is used and the superscript $b$ denotes the base case without the social login. Furthermore, it is assumed that CPs are symmetric in the base case, i.e., $u_A^b = u_B^b = u^b$.

Second, due to information sharing about the user, the targeting rates of CP $G$ and CP $s$ are increased by a factor of $\phi_G \geq 1$ and $\phi_s \geq 1$, respectively. Consequently,

$$\alpha_k = \begin{cases} \alpha_k^b, & \text{for the mass of users, } D_s\text{, of CP } s \text{ that does not use the social login} \\ \alpha_k^l = \min\{\phi_k \alpha_k^b, 1\}, & \text{for the mass of users, } D_s\text{, of CP } s \text{ that uses the social login.} \end{cases}$$

Again, it is assumed that special-interest CPs are symmetric in the base case, i.e., $\alpha_A^b = \alpha_B^b = \alpha_s^b$.

**Advertiser** The advertiser wants to place an informative ad that is targeted at a specific target audience. The goal of the advertiser is to generate attention for its product or service, which, e.g., can be a visit to its online- or offline-store some time after the ad has been viewed. The effectiveness of an ad is thus measured with respect to the rate of effective view-through (Hamman and Plomion, 2013), which includes the case of a click-trough, but also considers lagged responses of consumers (Asdemir et al., 2012; Bleier and Eisenbeiss, 2015). In particular, it is assumed that the value of the first ad impression that is displayed to a user belonging to the target audience is $v = 1$. Moreover,

[9] For example, the "Log in with Facebook" feature was unavailable for several hours in September 2015, preventing users to login at all CPs that used this social login (Burlacu, 2015).

because the ad is informative, it is assumed that all subsequent ad impressions on the same user are wasted and thus, do not create additional value for the advertiser (for a similar assumption see, e.g. D'Annunzio and Russo, 2015; Calvano and Jullien, 2012; Athey et al., 2014; Ambrus et al., 2016).[10] The objective of the advertiser is to select the subset of CPs at which to advertise in order to maximize its profit, i.e.,

$$\Pi_Z = \Gamma_A \left(n_A - p_A\right) + \Gamma_B \left(n_B - p_B\right) + \sum_{s=A,B} \Gamma_{G(s)} \left(n_{G(s)} - p_{G(s)}\right),$$

where $\Gamma_s$ ($\Gamma_{G(s)}$) is an indicator function, which returns one if an ad is placed for the mass of $D_s$ users at CP $s$ (CP $G$) and zero otherwise. Moreover, $n_s$ ($n_{G(s)}$) denotes the expected number of ad-relevant viewers from the total mass of users $D_s$ at CP $s$ (CP $G$) that see the ad for the first time and thus have a value of $v = 1$ for the advertiser. In order to keep the presentation concise $n$ will be referred to simply as "view-throughs" in the following.

**Structure and timing** The following four-stage game is considered:

*Stage 1*: The general-interest CP $G$ decides whether to offer a social login for the special-interest CPs $s$.

*Stage 2*: Special-interest CPs $s$ simultaneously but independently decide whether to adopt the social login and users decide which CP to use.

*Stage 3*: All CPs simultaneously set advertisement prices $p_k$.

*Stage 4*: The advertiser decides at which CPs to advertise.

[10] In fact, it is only required that the marginal value of subsequent ads is decreasing (cf. Anderson and De Palma, 2013). The assumption that subsequent views have zero marginal value is thus merely made to keep the analysis simple. Empirical research on advertising effectiveness shows that additional impressions of the same ad are indeed less valuable for the advertiser (see, e.g., the survey by Simon and Arndt, 1980).

## 7.3 Competitive effects of the social login and market outcomes

The subgame perfect equilibrium is determined by solving through backward induction, i.e., beginning in Stage 4 and proceeding backwards.

**Stage 4: Advertiser's decision** In order to decide at which CPs to advertise, $Z$ calculates the expected view-throughs per CP, $n_k$. Since the special-interest CP $s$ is only in competition with CP $G$ for views, it suffices to consider only the mass of users at CP $s$, i.e., $D_s$. In the first period every ad impression will be the first for a visitor, so that CP $s$ expects view-throughs of $n_{s,1} = \alpha_s\, \delta D_s$. In reverse, the remaining $D_s - \delta D_s$ users have visited CP $G$ in the first period, and thus CP $G$ expects $n_{G(s),1} = \alpha_{G(s)}(D_s - \delta D_s)$ view-throughs in the first period from the mass of users that multi-home between CP $s$ and CP $G$. Recall that CP $G$'s targeting rate can differ between different masses of users, $D_s$, because it depends on whether or not CP $s$ has adopted the social login. This is denoted by $\alpha_{G(s)}$. In the second period, only those users are relevant for the advertiser that have not seen the ad in the first period at any of the two CPs, i.e., $D_s - n_{s,1} - n_{G(s),1}$. Note that in period two, the mass of users $D_s$ again redistributes its attention randomly between CP $s$ and CP $G$ according to $\delta$, i.e., users that have been targeted at CP $s$ may now visit CP $G$, and vice versa. Thus, CP $s$ and CP $G$ expect to generate $n_{s,2} = \alpha_s\delta(D_s - n_{s,1} - n_{G(s),1})$ and $n_{G(s),2} = \alpha_{G(s)}(1-\delta)(D_s - n_{s,1} - n_{G(s),1})$

new view-throughs in the second period, respectively. In summary, this yields a total number of view-throughs by CP $k$ of[11]

$$n_s = \underbrace{\alpha_s \delta D_s}_{\text{period t = 1}} + \underbrace{\alpha_s \delta (D_s - \alpha_s \delta D_s - \alpha_{G(s)}(D_s - \delta D_s))}_{\text{period t = 2}} \tag{7.1}$$

$$n_G = \sum_{s=A,B} \underbrace{\alpha_{G(s)}(D_s - \delta D_s)}_{\text{period t = 1}} + \underbrace{\alpha_{G(s)}(1-\delta)(D_s - \alpha_s \delta D_s - \alpha_{G(s)}(D_s - \delta D_s))}_{\text{period t = 2}}. \tag{7.2}$$

It is important to see that $n_k$ does not only depend on CP $k$'s own targeting rate, $\alpha_k$, but also on the other CP's targeting rate. This is the basis for competition between the CPs in the advertising market. With regard to the mass of users $D_s$, the advertiser faces the decision to display advertising either exclusively at CP $s$ or CP $G$, or at both outlets at the same time. Obviously, the latter option maximizes view-throughs $n = n_{G(s)} + n_s$. However, the advertiser maximizes profit $\Gamma_s(n_s - p_s) + \Gamma_{G(s)}(n_{G(s)} - p_{G(s)})$ and may decide to switch exclusively to a CP if it can gain a higher net benefit through a lower price $p$ for the view-throughs. For example, the advertiser will decide to reach the mass of $D_s$ consumers exclusively through CP $s$ if $n_s^e - p_s > \sum_{m=G(s),s}(n_m - p_m)$. Thereby $n_s^e$, which denotes the total view-throughs at $s$ when CP $s$ is the advertiser's exclusive outlet, is larger than CP $s$'s total view-through when CP $s$ is not exclusive. This is because CP $s$ can generate more view-throughs in the second period, as users have not been able to view the advertisement already at the other CP in the first period. The advertiser's decision where to advertise will thus depend on view-throughs, as identified above, and CPs' prices, which are determined next.

**Stage 3: CPs' ad pricing** First, see that exclusive advertising cannot be an equilibrium outcome, because CPs do not have marginal costs of advertising and thus the excluded CP, which currently experiences zero profits from advertising, would always be better

[11]Note that it has been implicitly assumed that the advertiser has chosen to display the ad at all CPs, which is indeed the equilibrium outcome. A complete characterization of the model would also require to specify $n_k$ in those cases in which the advertiser choose only a proper subset of the CPs. It is easy to see that $n_k$ can then be derived by setting $\alpha_k = 0$ for all CPs that are not chosen by the advertiser.

off by lowering its advertising price, such that it may be considered again by advertiser $Z$. This competition for selection by $Z$ constrains the CPs' advertising prices. In equilibrium prices must therefore be chosen such that $Z$ is indifferent between selecting both CPs and selecting one CP exclusively. Hence, equilibrium prices can be derived by solving the following system of equations

$$n_{G(s)} - p_{G(s)} + n_s - p_s = n^e_{G(s)} - p_{G(s)} \tag{7.3}$$

$$n_{G(s)} - p_{G(s)} + n_s - p_s = n^e_s - p_s, \tag{7.4}$$

which yields equilibrium prices of $p^*_k(D_s, \alpha_s, \alpha_{G(s)})$. Note that equilibrium prices (and thus CPs' equilibrium profits) behave intuitively with respect to changes in the targeting rate. For example, in line with Athey and Gans (2010), a higher targeting rate, which in turn yields more view-throughs, allows CPs to demand a higher equilibrium price $p^*$ and thus yields higher profits, i.e., $\frac{\partial \pi^*_k}{\partial \alpha_k} > 0$. Moreover, competition between CPs yields a negative effect of the rival's targeting ability on a CP's equilibrium profit, i.e., $\frac{\partial \pi^*_s}{\partial \alpha_{G(s)}} < 0$, and $\frac{\partial \pi^*_{G(s)}}{\partial \alpha_s} < 0$, respectively.

**Stage 2: Special-interest CPs' social login adoption** Provided the social login is offered by CP $G$, each CP $s$ decides independently whether to adopt the social login by comparing anticipated advertising profits $\Pi^*_k$ given targeting rates $\alpha_k$ and market share $D_s$. More specifically, each CP $s$ trades off the positive effect on consumers' valuation for their services and/or a potentially improved advertising effectiveness against the negative effect of intensified competition in the advertising market. On the one hand, the adoption of the social login increases the special-interest CP's base utility by $\theta$, which may generate a competitive advantage over the other special-interest CP and expand its market share from $D^b_s$ to $D^l_s$. However, if the rival CP also adopts the social login, then both CPs offer the same base utility again and thus, $D^b_s = D^l_s$. Moreover, the social login may improve the special-interest CP's targeting rate based on the additional information over its users and therefore increases its advertising effectiveness, i.e., $\alpha_s^l = \phi_s \alpha_s^b$, with $\phi_s \geq 1$. On the other hand, data sharing may also improve the general-interest CP's targeting rate, i.e., $\alpha_{G(s)}^l = \phi_G \alpha_{G(s)}^b$, with $\phi_G \geq 1$, which negatively affects the special-interest CP's advertising revenues, as shown above. In summary, four different scenarios can be distinguished: Either both special-interest CPs adopt (scenario $l,l$) or do not adopt (scenario $b,b$) the social login, or only one CP adopts the social login (scenarios $l,b$ and $b,l$). The resulting normal form game is summarized in Table 7.1 and the corresponding profits are derived in Appendix A.4.

TABLE 7.1: *Normal form game representing special-interest CPs' social login adoption decision.*

| | | **CP** *B* | |
|---|---|---|---|
| | | Social Login (l) | No Login (b) |
| **CP** *A* | Social Login (l) | $(\Pi_A^{l,l},\Pi_B^{l,l})$ | $(\Pi_A^{l,b},\Pi_B^{b,l})$ |
| | No Login (b) | $(\Pi_A^{b,l},\Pi_B^{l,b})$ | $(\Pi_A^{b,b},\Pi_B^{b,b})$ |

In the following, it is shown that if special-interest CPs are symmetric, either both or none adopt the social login. Thereby, CP $s$ considers the net effect $\Delta_{l,d-b,d} := \Pi_s^{l,d} - \Pi_s^{b,d}$ of the social login on its anticipated profits, given its rival's decision $d \in \{b,l\}$. CP $s$ adopts the social login, given that its rival does not adopt it, if and only if $\Delta_{l,b-b,b} := \Pi_s^{l,b} - \Pi_s^{b,b} > 0$, which is satisfied if its increase in targeting rate is above the critical threshold

$$\begin{aligned}\overline{\phi_s} \geq \frac{1}{\delta\,\alpha_s^b\,(\tau+\theta)} \cdot \Bigg( &\Big(\alpha_{G(s)}^b\,(\delta-1)\,(\tau+\theta)\phi_G + \tau + \theta\Big) \\ &- \Big([((\phi_G\,\alpha_{G(s)}^b\,(\delta-1))^2 + 2\alpha_{G(s)}^b(\delta-1)(\phi_G - \delta\alpha_s^b) + (\delta\alpha_s^b - 1)^2)\tau \\ &+ \theta(\tau+\theta)(1+\phi_G\alpha_{G(s)}^b(\delta-1))^2]\,(\tau+\theta)\Big)^{1/2}\Bigg).\end{aligned} \tag{7.5}$$

On the other hand, CP $s$ adopts the social login, given that its rival also adopts it, if and only if $\Delta_{l,l-b,l} := \Pi_s^{l,l} - \Pi_s^{b,l} > 0$, which is satisfied if its base-targeting rate does not exceed the critical threshold

$$\begin{aligned}\overline{\overline{\phi_s}} \geq \frac{1}{\delta\,\alpha_s^b\,\tau} \cdot \Bigg( & \Big(\alpha^b_{G(s)}\,(\delta-1)\,\tau\,\phi_G + \tau\Big) \\ & - \Big([\tau\,(\phi_G\,\alpha^b_{G(s)}\,(\delta-1))^2 + 2(\delta-1)(\alpha^b_{G(s)}(\tau\phi_G - \delta(\tau-\theta)\alpha_s^b) \\ & + (\delta+\alpha_s^b)^2(\tau-\theta) - 2\delta(\tau-\theta)\alpha_s^b + \tau)]\tau\Big)^{1/2}\Bigg).\end{aligned} \tag{7.6}$$

As special-interest CPs are symmetric and decide simultaneously, it follows directly that both CPs will adopt the login (universal adoption) whenever $\Delta_{l,b-b,b} > 0$ and no CP will adopt the login otherwise.[12] Due to the symmetry of the special-interest CPs, in both cases $D_s = 1/2$.

In situations where both CPs $A$ and $B$ have an unilateral incentive to adopt the login, i.e., $\Delta_{l,b-b,b} > 0$, resulting profits under universal adoption may not necessarily exceed profits in the initial setting without the login. Instead, special-interest CPs may find themselves in a prisoner's dilemma-like situation, where relative competitive benefits due to the social login cancel out if the other CP adopts the social login as well. In consequence, increased advertising competition by the general-interest CP $G$ due to information sharing via the social login may outweigh any positive impact on CP $s$'s own targeting rate. This is the case if $\Delta_{l,l-b,b} := \Pi_s^{l,l} - \Pi_s^{b,b} < 0$, which is satisfied if and only if

$$\begin{aligned}\widehat{\phi_s} < \frac{1}{\delta\,\alpha_s^b} \cdot \Bigg( & \Big(\alpha^b_{G(s)}\,(\delta-1)\,\phi_G + 1\Big) \\ & - \Big((\phi_G\,\alpha^b_{G(s)}\,(\delta-1))^2 + 2(\delta-1)\alpha^b_{G(s)}\,(\phi_G - \delta\alpha_s^b) + (\delta\alpha_s^b - 1)^2\Big)^{1/2}\Bigg).\end{aligned} \tag{7.7}$$

[12] Formally it can be shown that $\overline{\phi_s} > \overline{\overline{\phi_s}}$.

**Stage 1: General-interest CP's social login offer** Anticipating special-interest CPs' adoption decision and ensuing effects on advertising prices, the general-interest CP decides whether or not to offer the social login. To this end CP $G$ weighs the positive effect on its own targeting ability against the negative effect of the rival's improved targeting ability, both of which will affect competition in the advertising market. In general, CP $G$ is willing to offer the social login if $\Upsilon_{l,l-b,b} := \Pi_G^{l,l} - \Pi_G^{b,b} > 0$, since the symmetric special-interest CPs always make the same adoption decision. This condition is satisfied if

$$\widetilde{\phi_s} < \frac{\alpha^b_{G(s)}\,(\phi_G^2 - 1)\,(\delta - 1) + 2\,(\delta\alpha^b_{G(s)} + \phi_G - 1)}{2\,\delta\,\phi_G\,\alpha^b_s}. \tag{7.8}$$

**Possible market outcomes:** Based on the previous analysis and the therein derived thresholds, the feasible market outcomes that may arise can now be fully characterized. As special-interest CPs are symmetric, it will generally suffice to consider any submarket $D_s$ to discuss the possible market outcomes. Thereby, it is most insightful to delineate the different market outcomes in terms of CP $s$'s and CP $G$'s increase in targeting rate due to the social login. In particular, the market outcomes are determined by the critical thresholds i) $\overline{\phi_s}$, ii) $\widehat{\phi_s}$ and iii) $\widetilde{\phi_s}$ derived above, that denote i) when the special-interest CPs adopt the social login, ii) when special-interest CPs are actually better off by adopting the social login, and iii) when the general-interest CP offers the social login.

In total there are six possible market outcomes, which are illustrated in Figure 7.2.

*I*: The social login is offered and adopted. All CPs are better off, i.e., profits with the social login are higher than without it.

*II*: The social login is offered and adopted. Whereas the general-interest CP is better off, special-interest CPs are worse off (prisoner's dilemma-like outcome).

*III*: The social login is not offered, but special-interest CPs would be willing to adopt it. However, adoption would make them worse off.

*IV*: The social login is offered, but special-interest CPs do not adopt it.

*V*: The social login is not offered, but special-interest CPs would be willing to adopt it. Adoption would make them better off.

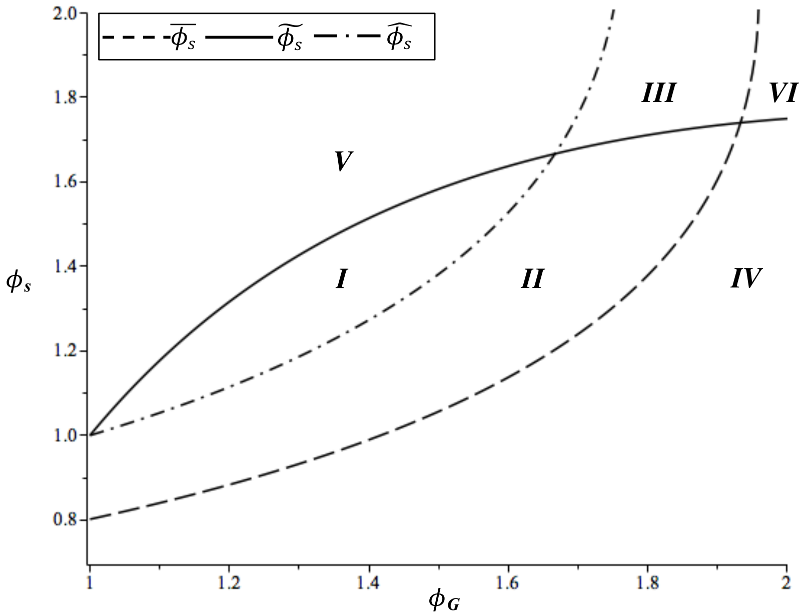
*VI*: The social login is neither offered nor would it be adopted by special interest CPs. All CPs would be worse off with the social login.

Evidently, the social login is either not offered, or not adopted, or both in market outcomes $III$ - $VI$. Furthermore, it is immediately obvious that the social login is neither always offered nor always adopted when it would be socially optimal. First, the social login is always beneficial to consumers, who experience an increase in base utility by $\theta$, everything else being equal. Thus, the market outcomes $III$ to $VI$ are inefficient with respect to consumers surplus, because the social login is not offered or not adopted here. Moreover, in market outcome $II$ special-interest CPs are worse off despite the fact that they have voluntarily adopted the social login. Finally, in market outcome $V$ special-interest CPs would be better off by using the social login, but are not offered this option. Consequently, in five of the six possible market outcomes a market failure may occur, whereas only in outcome $I$ the market outcome is always efficient.

**RESULT 7.1.** *In market outcome $II$ (voluntary) adoption of the social login leaves the special-interest CPs worse off. Generally, provision of the social login may create market failures in market outcomes $II$ to $VI$, whereas it is always efficient in market outcome $I$.*

**Comparative statics** Subsequently, the conditions under which the social login is offered and adopted are further examined. Therefore, it is investigated how the critical thresholds $\overline{\phi_s}$, $\widetilde{\phi_s}$ and $\widehat{\phi_s}$ change ceteris paribus in response to a change in one of the model's exogenous parameters. While the details of the comparative statics are rele-

FIGURE 7.2: *Illustration of possible market outcomes: The social login is offered in outcomes I, II and IV and not offered otherwise. The social login is adopted in outcomes I and II and not adopted in outcome IV. In outcome I special-interest CPs are better off and in outcome II they are worse off by adopting the social login. Note: The figure is derived for $\alpha_s^b = 0.5, \alpha_{G(s)}^b = 0.5, \tau = 0.5, \theta = 0.1, \delta = 0.5$. Not all market outcomes may exist for all feasible parameter constellations.*



gated to Appendix A.4, it can be concluded that the model yields quite intuitive results. An increase in the CPs' targeting rate without the login, $\alpha_s$ for CP $s$ ($\alpha_{G(s)}$ for CP $G$), makes it less likely for CP $s$ (CP $G$) to adopt (offer) the social login. A similar effect can be observed for an increase in a CP's screen attention, $\delta$ for CP $s$ ($(1-\delta)$ for CP $G$), which translates into the same effect as if one's own targeting rate is increased while simultaneously the rival's targeting rate is decreased. Overall an increase in one's own screen attention therefore decreases incentives for the adoption (for CP $s$) and the offer (for CP $G$) of the social login.

The parameters $\alpha_{G(s)}$, $\alpha_s$ and $\delta$, which affect the competition in the advertising market, impact all three critical thresholds. By contrast the parameters $\theta$ and $\tau$, which affect the competition for users between special-interest CPs, impact only threshold $\overline{\phi_s}$. Intuitively, as users' benefit of the social login increases (increase in $\theta$) or as the competition for users becomes weaker (decrease in $\tau$), the social login becomes less relevant for the competition for users and thus, it is adopted less likely by the special-interest CPs.

**RESULT 7.2.** *As a special-interest (general-interest) CP's targeting rate or screen attention increases, it becomes less attractive to adopt (offer) the social login. The more special-interest CPs are in competition for users, the more the social login is adopted.*

**Illustrative market scenarios** To conclude the analysis two specific market scenarios are highlighted that are illustrative in the sense that they represent extrema of the feasible spectrum of possibilities.

First, consider the case where the special-interest CPs have already attained a high targeting rate and thus only the general-interest CP will be able to increase its targeting rate due to information sharing via the social login, i.e., $\phi_G > \phi_s \equiv 1$. In this case the special-interest CP cannot gain a competitive advantage in the advertising market from adopting the social login. It will base its adoption decision therefore purely on the expected impact of the social login on the competition for users. In particular, if $\theta > 0$ the prisoner's dilemma-like situation will prevail, as special-interest CPs are symmetric and none can commit not to use the social login. Eventually both will adopt the login and compete again head to head, each attaining 50 percent market share. In the end, only the general-interest CP, and, of course, the consumers, benefit from the social login. From Figure 7.2 it is easy to see that at $\phi_s = 1$ only two market outcomes are feasible. The general-interest CP will always offer the social login and either both special-interest CPs adopt it and are worse off (outcome $II$), or they do not adopt it (outcome $IV$).

Second, consider the polar case where the social login does not offer any net benefit to consumers, i.e., $\theta = 0$. In this case the special-interest CPs will base their decision whether or not to adopt the social login purely on the effect in the advertising market. This means that $\overline{\phi_s}$ and $\widehat{\phi_s}$ coincide in this case, because special-interest CPs will only adopt the social login if and only if it is eventually profitable for them. Thus, market outcomes $II$ and $III$ do not exist and the prisoner's dilemma-like situation does not arise here.

## 7.4 Discussion

Social logins are single sign-on solutions provided predominantly by social networking sites that allow users to register with and login at otherwise unaffiliated CPs using their existing login credentials of the social network. While a social login provides added value to the website users, they also imply that user data is shared between the CP that employs the social login and the social network that offers it. Whereas the former effect is relevant for the competition for website visitors, the latter effect is relevant for the competition in the advertising market, as data sharing improves the websites ability to offer targeted advertising. The presented model captures these two dimensions of competition and identifies the winners and losers with regard to the usage of social logins in the various market outcomes that may arise. In particular, it is shown that the adoption of the social login may yield a prisoner's dilemma-like situation for the CPs. The competition for users may induce them to adopt the social login, but eventually they may stand to lose their competitive advantage over the social networking site in the advertising market. Moreover, it is demonstrated that social logins are likely to yield a market failure because the login is not offered in cases where it would be beneficial for users and the advertiser.

Although the model considers only a particular submarket, it is evident from the analysis that the social network wishes to offer the login only to those CPs from which it can profit relatively more (in terms of increase in its targeting rate) than the content provider that employs the social login. Indeed, although Facebook generally allows every content provider to employ the social login, it lays out in its platform policy that it may "enforce against [a] [...] website if [Facebook] concludes that [it] violates [its] terms or is negatively impacting the platform" and that in this case it "may or may not notify in advance".[13] Thus, this analysis also raises an important policy question that is related to the debate on net neutrality (Krämer et al., 2013; Easley et al., 2015) and on Open Access (see Chapter 2). The Open Access debate at the telecommunications infrastructure layer centers around the question to what extent the operator of an access network is allowed to discriminate between retailers that rely on access to the network infrastructure. Hence, the network operator as a gatekeeper controls the access to an essential upstream resource. Similarly one can raise the question here whether Facebook, who is also an important gatekeeper with regard to its mostly unique personal data resources, should be allowed to discriminate between different content providers in providing access through its Facebook login. Given the analysis in this chapter, it

[13]See `https://developers.facebook.com/policy`, "Things you should know", number 6. Accessed March 14, 2016.

is demonstrated that market failures may occur and thus there potentially is room for welfare improving policy interventions.

Finally, possible model extensions and limitations are highlighted. First, the presented analysis starts from the premise that the adoption of the social login provides a net benefit to consumers. However, the model could be extended to also incorporate a net loss in users' utility, e.g., due to privacy concerns. In this case, the prisoner's dilemma would be reversed in the sense that special-interest CPs may not adopt the social login although it would be beneficial to them. Second, special-interest CPs are assumed to be symmetric. Although this is the obvious starting point, a much richer set of market outcomes may arise in case CPs are asymmetric, e.g., with respect to their targeting rates ex-ante, or with respect to their increase in net utility or targeting rate ex-post. The prisoner's dilemma-like situation may also be mitigated if markets were not fully covered or if a CP would enjoy some additional elastic demand from users that does not come from the rival CP. Third, some of the model parameters that are currently treated as independent and exogenous may in fact be correlated and partially endogenous. For example, the screen attention may depend on the net benefit that a CP offers, or a CP's targeting rate may depend on its demand. This will likely amplify the already observed effects. At last, the presented analysis considers a monopolistic login provider as well as a monopolistic advertiser. Although this seems to represent a reasonable assumption with respect to the presence of market power and network effects in online content and digital services markets, it may be worthwhile to extend the analysis to competing login providers and advertisers, respectively.

# Chapter 8

# Conclusion

THIS thesis studies the competitive and cooperative interactions in information and communications technology markets, where firms require access to an essential competitive resource. In the light of continuous technological innovation, firms and policy makers alike are challenged by the consequences of transforming market structures in the telecommunications industries and the emergence of new digital services markets. As outlined in this thesis, combining theoretical analysis and experimental evaluation provides a methodological foundation to examine market outcomes under institutions that may govern these markets. By serving as a testbed for policy proposals, this work aims at identifying the welfare implications of designated institutions and informing the design of new regulatory institutions prior to their implementation in the field. Specifically, the concept of Open Access is scrutinized with regard to its implications for competition and its ultimate impact on consumers. The insights and conclusions drawn from these investigations thus contribute to the scientific discourse, but also support policy makers and practitioners when assessing the implications of competitive and cooperative strategies in ICT markets.

## 8.1 Summary and implications

In the following, the main findings of this thesis are summarized and discussed with respect to their methodological and policy implications. The section is organized along the research questions set out in Chapter 1.

Addressing Research Question 1, this thesis proposes a unified definition of Open Access based on various notions offered by different stakeholders in the context of telecommunications infrastructure markets. According to this understanding, Open Access, in essence, mandates that access to an upstream resource is provided in a non-discriminatory manner. In situations where the upstream resource is provided by a vertically integrated firm this requires non-discrimination between the integrated downstream subsidiary and an independent retailer as well as non-discrimination between two independent retailers. Chapter 2 demonstrates that Open Access may thereby be achieved by a range of alternative regulatory institutions. At a fundamental level, these institutions may differ with regard to i) the vertical structure that is allowed or prescribed at the supply-side of the upstream resource, ii) the degree and form of public-sector participation, and iii) the level of access and the corresponding wholesale products.

In consequence, the choice for a specific regulatory institution involves several trade-offs that must be recognized by authorities and policy makers. More generally, the surveyed economic literature points to a trade-off between static and dynamic efficiency that each regulatory institution balances differently. Based on the effects identified in the theoretical and empirical literature, Chapter 2 suggests a guideline to assist policy makers and regulatory agencies in their decisions according to their primary objective. In this vein, it is made explicit that regulatory policy needs to weigh and prioritize objectives. To this end, traditional regulatory institutions such as price regulation and vertical separation have been examined thoroughly by the extant literature. In contrast, the review points to research gaps with regard to alternative regulatory regimes which may be better suited to balance the efficiency trade-off. Most notably, a regime based on mandated non-discrimination may be able to safeguard competition by creating a level playing field, but at the same time foster investment incentives as wholesale charges are not subject to ex ante price regulation.

Margin squeeze regulation, in particular, has been proposed as an alternative institution to price regulation and referred to as a possible means to ensure Open Access in telecommunications markets where infrastructure competition has been established. Previous investigations of margin squeeze regulation, however, have predominantly been concerned with the application in markets with a single dominant supplier of the wholesale resource. Therefore, Research Question 2 aims specifically at a market structure, where a second integrated firm is able to self-supply the upstream good. Chapter 4 examines whether margin squeeze regulation could improve market outcomes relative to no regulation in the case of a wholesale monopoly based on a game-theoretic model. This market scenario resembles the current situation in many fixed telecommunications markets. Although margin squeeze regulation may prevent foreclosure and thus could be beneficial for independent retailers, consumers are found to be unambiguously worse off due to higher retail prices. Remarkably, total welfare may increase in some cases, due to higher producer surplus under margin squeeze regulation. These findings contradict the rationale underlying the current legislative implementation in Europe: competing infrastructures do not represent exogenous competitive constraints as assumed, but are likely to react strategically to the implementation of new regulatory rules. In consequence, rather that the wholesale price level falls, the overall retail price level rises under margin squeeze regulation.

Empirical evidence from a laboratory experiment provides further support for the theoretical findings that margin squeeze regulation does not benefit consumers in a market characterized by infrastructure competition and a wholesale monopoly. Moreover, Chapter 5 extends the analysis of margin squeeze regulation to wholesale competition, i.e., a market scenario where both integrated firms may offer wholesale access to their respective upstream resource. In this scenario, theory would predict that margin squeeze regulation benefits consumers, as foreclosure is prevented and the competitive outcome remains as the single equilibrium prediction. However, experimental evidence contradicts this prediction as consumer welfare does not increase under margin squeeze regulation compared to no regulation. In fact, empirical findings indicate that under regulation retail market prices may increase to the detriment of consumers, especially in cases where wholesale competition is effective in reducing prices below the monopoly level. On the contrary, margin squeeze regulation may allow the retailer to obtain higher profits due to lower access prices only in cases where a high degree of tacit collusion among integrated firms impedes effective wholesale competition. As findings on margin squeeze regulation contrast conventional wisdom and the intuitive appeal of its justifying rationale, the general need for thorough theoretical and experimental evaluation of policy proposals is emphasized.

Infrastructure competition has often been articulated as the ultimate goal of sector-specific regulation and may thus be viewed as a sufficient criterion to abstain from price regulation. Furthermore, previous theoretical studies have pointed to wholesale competition as an effective means to achieve Open Access for independent retailers at the competitive wholesale price (cf. Ordover and Shaffer, 2007; Brito and Pereira, 2010; Bourreau et al., 2011). These studies, however, do not take into account the possibility of tacit collusion, which is frequently observed in markets with only few integrated competitors (Parker and Röller, 1997). Therefore, Chapter 5 investigates Research Question 3 and yields the following result: wholesale and retail prices are found to be higher under wholesale competition than under a wholesale monopoly. The surprising finding that consumers are in consequence worse off under competition is rationalized by an investigation of collusion incentives in an infinitely repeated game context. It is shown that the symmetric market structure under wholesale competition facilitates tacit collusion relative to the asymmetric market structure under a wholesale monopoly. In the latter case, the vertically integrated firm that does not provide access, benefits relatively less from tacit collusion. Moreover, it has a stronger incentive to price more aggressively in the retail market as it does not face any opportunity costs in the form of foregone wholesale revenues. In conclusion, these results point to a more general dilemma of the Open Access rationale: whereas non-discrimination may provide the basis for competition on equal terms, symmetry may facilitate coordinated behavior among competitors to the detriment of consumers. In this vein, tacit collusion may constitute a primary concern above and beyond the exercise of market power. Therefore, it is of particular interest that a complementary price commitment rule—which does not change the theoretical prediction—significantly decreases the empirically observed degree of tacit collusion and in consequence leads to significantly lower market prices as well as higher consumer surplus.

The relevance of tacit collusion for competition in concentrated markets motivates Research Question 4, which asks for the relationship between the number of competitors and the degree of tacit collusion in a market. A meta-analysis of experimental studies that have varied the number of firms provides general support for the notion that markets with a larger number of firms are less prone to tacit collusion than markets with a lower number. In particular, previous studies confirm a significant negative effect on tacit collusion from four to two as well as from three to two firms. Suprisingly, the extant experimental literature does not provide empirical evidence for a significant effect from four to three firms under either Bertrand or Cournot competition, and therefore cannot substantiate the assumption of a strictly monotonic number effect on tacit collusion. Therefore, Chapter 6 conducts two experimental studies with symmetric and asymmetric distributions of market power that systematically investigate number effects for two, three and four firms, while also controlling for the competition model. Based on a considerably larger number of independent observations compared to the surveyed studies, the experiments find evidence for a significant number effect on tacit collusion from four to three firms as well as from three to two firms. In fact, the empirically observed increase in the degree of tacit collusion relative to the Nash equilibrium is almost identical from four to three as it is from three to two. Indeed, this suggests a linear number effect on the degree of tacit collusion for highly concentrated oligopolies. Furthermore, the experimental evidence contributes to the notion that asymmetry between firms impedes coordinated behavior and leads to lower degrees of tacit collusion compared to a symmetric market structure. Notably, market outcomes remain significantly above the theoretical prediction even in markets with four firms, demonstrating subjects' robust ability to sustain tacit collusion—even under a finite time horizon.

From a methodological perspective it is important to recognize the relevant design dimensions that affect the degree of observed tacit collusion in economic laboratory experiments. In this spirit, Research Question 5 is concerned with the consequences of conducting competitive interactions in continuous rather than discrete time. Therefore, Section 3.3 classifies extant studies in non-discrete time and then conducts an experiment to compare tacit collusion under continuous and discrete time, while controlling for the competition model and the number of firms. In contrast to previous studies, which have found that continuous time facilitates cooperation, e.g., in a prisoner's dilemma context (Friedman and Oprea, 2012), the obtained empirical evidence suggests that tacit collusion in an oligopoly competition context is significantly lower with a continuous framework than with a discrete framework. This finding bears important methodological implications. First, it may inform the design of future oligopoly experiments with regard to the consequences of the chosen mode of interaction (continuous vs. discrete). Second, these findings may be taken into account when results of oligopoly experiments in discrete time—which applies to the vast majority of the extant experimental literature—are generalized to a context that is rather characterized by continuous time. This is the case whenever decision makers can decide on the timing of an action endogenously and thus asynchronous interaction may occur. Finally, given the contrasting findings in previous comparisons of continuous and discrete time, the results suggest that whether continuous time facilitates or impedes cooperation hinges critically on the specific game context.

Above and beyond the telecommunications infrastructure layer, Research Question 6 addresses the implications of voluntary access relationships among competitors at the digital services layer. To this end, Chapter 7 examines the competitive effects of social logins that allow for the sharing of user and usage data between online content providers and social networks. It is shown that content providers may adopt the social login even if this strategic decision makes them ultimately worse off, i.e., they find themselves in a prisoner's dilemma-like situation. The rationale for adoption is based on the relative advantage that a content provider can gain over its horizontal competitor by sharing information with the social network. However, this advantage is offset if all content providers decide to adopt the social login. In doing so, the content providers allow the social network—the provider of the social login—to access a superior data basis and to increase its revenues in the advertising markets through a higher targeting rate. Moreover, the analysis shows that the social network has incentives to discriminate between content providers if it can offer the social login on a discretionary basis. More specifically, it may not offer the social login if this would threaten its position in the advertising market relative to the respective content provider. In conclusion, this shows that voluntary access regimes do not necessarily ensure Open Access with regard to data resources. In consequence, consumers may be worse off. On the contrary, voluntary access offers may be implemented by a dominant gatekeeper to protect its position, albeit not through exclusion, but through exploitation.

## 8.2 Limitations and outlook

This thesis has several limitations with regard to its scope and its methodology that point to promising avenues for future research. Whereas, limitations specific to each study are discussed in the respective chapters, this section is dedicated to a summary of the overreaching issues.

Foremost, the studies in this thesis analyze the underlying issues from a purely static perspective and do not explicitly consider effects on dynamic incentives. More specifically, the thesis focusses on the question which institutions might improve static market outcomes compared to alternative institutions, in particular to the benchmark scenario of no regulation. Thus, the implicit premise is that regulatory regimes which abstain from price regulation are more likely to have a positive effect on dynamic incentives. This reasoning is based on the trade-offs between static and dynamic objectives identified for regulatory institutions in telecommunications infrastructure markets in Chapter 2, and the growing empirical evidence on the chilling effects of wholesale price regulation (inter alia Briglauer et al., 2013; Bacache et al., 2014) on investment incentives. Moreover, a trade-off between static and dynamic efficiency has long been recognized in economic theory going back to Schumpeter (1942) and found to apply to a more general context than infrastructure markets and price regulation (Aghion et al., 2005). Yet, there is an ongoing academic discussion about the more precise characterization of the trade-off's functional form (Sacco and Schmutzler, 2011; Hashmi, 2013) and potential interaction effects with varying market characteristics (Gilbert, 2006). With regard to the current developments in telecommunications markets as well as antitrust cases in digital services markets, the necessity to understand the relationship between static and dynamic effects in specific application scenarios is only expected to grow (Bauer, 2014; Parker and Van Alstyne, 2014). In these antitrust cases, authorities and courts are regularly challenged to weigh the benefits of competitive markets in a static sense against incentives for innovative activity. Therefore, additional theoretical, experimental, and empirical work is required to inform those decision makers about the consequences of alternative regimes with regard to specific application scenarios and to explore and design institutions that can balance the general efficiency trade-off.

From a methodological perspective this calls for further research on how laboratory experiments can be employed to investigate and compare dynamic effects across institutions. The evaluation of investment decisions thereby presents several challenges because path dependencies and experimental subjects' unobserved strategic reasoning considerably affect experimental outcomes. Most notably, experimental subjects need to form expectations about future market interactions and associated payoffs when faced with investment decisions. Yet, these expectations may not realize accordingly, and in consequence, subjects may base their subsequent decisions on *forward induction*, i.e., behavior that rationalizes past decisions, rather than *backward induction*, which is regularly assumed in the theory to be tested. Whereas this issue can be mitigated through a more constrained experimental design, i.e., a higher degree of experimental control, such measures may limit the "behavioral freedom" of experimental subjects (Morgan, 2005). In consequence, this may prevent interesting effects in the interplay between dynamic and static considerations to arise in the first place. Nevertheless, studies that have examined investment decisions in an economic laboratory context point to potential approaches that can alleviate the aforementioned issues and provide a methodological basis for future inquires (see, inter alia, Darai et al., 2010; Sacco and Schmutzler, 2011; Aghion et al., 2014; Krämer and Vogelsang, 2016). In particular, Sacco and Schmutzler (2011) query subjects' beliefs in the investment stage and are thus able to relate actions in subsequent periods to those beliefs. Future experimental work may therefore focus on identifying and capturing individuals' strategic rationales at the micro level without unintentionally framing and interfering with those decisions.

Two general shortcomings of the experimental method apply to this thesis in particular. First, recent methodological analyses and replication studies have raised general concerns about the robustness and generalizability of individual empirical studies (Ioannidis, 2005; Simmons et al., 2011). Most notably, life sciences (Prinz et al., 2011; Begley and Ellis, 2012) and psychological science (Open Science Collaboration, 2015) have found themselves in a "credibility crisis" in consequence of a "reproducability crisis" (Baker, 2016). As a result, these disciplines have introduced additional mechanisms and increased efforts to improve the reliability and robustness of empirical findings (see, e.g., Nosek et al., 2015). On the one hand, pre-registration of study designs (Schulz et al., 2010) is emphasized in order to avoid false positive findings and minimize flexibility in data collection and analysis (Schwab et al., 2011; Simmons et al., 2011) as well as to mitigate publication bias (Easterbrook et al., 1991). On the other hand, ex ante statistical power analysis is traditionally required for medical trials in order to minimize false negative findings, i.e., erroneous findings of non-significance despite a true effect (Lachin, 1981; Lenth, 2001; Button et al., 2013). Finally and foremost, large replication programs have been initiated to corroborate robustness of findings by individual studies (e.g., Errington et al., 2014; Klein et al., 2014).

In experimental economics, similar efforts are desired to safeguard scientific credibility through replication efforts that assess robustness of findings and methodological standards that minimize confirmation bias (Roth, 1994). A recent replication study of laboratory experiments (Camerer et al., 2016) and methodological guidelines regarding statistical power analysis for economic experiments (List et al., 2011; Bellemare et al., 2014) represent starting points for further activities in this regard. In the spirit of Engel (2007) and Suetens and Potters (2007), empirical meta-analyses as conducted in Chapter 6 can shed light on the generalizability of findings by individual studies. In particular, the parametrization decisions made in this thesis may be subject to future robustness tests. As the parametrization of variables is inherently required when models are used as experimental instruments (see Chapter 3), the ensuing effects of specific parameter sets and their generalizability bear important practical and methodological implications.

The second general concern regarding economic experiments that study firm behavior in a laboratory context is the lack of external validity. Although shortcomings in this regard are inherent in the experimental methodology—which aims at internal validity as the primary objective (Guala, 2005)—there are possible approaches to mitigate those shortcomings. First, external validity may be tested in experimental studies that go beyond pure student samples and instead include experts and practitioners within the designated context of application. Chapter 5, for instance, conducts a validation study with expert subjects from the telecommunications industry, which allows for a comparison of outcomes with the student relative to the practitioners sample. Note, however, that the inclusion of expert subjects involves additional challenges that need to be considered in the design and implementation of such validation studies. Experts may introduce implicit additional considerations based on their everyday experience into the laboratory that however are not considered in the experimental context or even the underlying theory (Ball and Cech, 1996). Additional questionnaires and comprehension tests can help to make these implicit assumptions and expectations explicit. In turn, this allows experimenters to reinforce experimental control ex ante or at least allow for control ex post by considering peculiarities in the analysis of experimental outcomes.

A further step to address external validity above and beyond the laboratory context is the implementation of experimental field studies (Einav and Levin, 2010). In particular, electronic markets and digital services may allow for controlled variation of market institutions directly in the designated application context (see the discussion in Levin, 2013). In regulatory practice, new institutions may be implemented first in pilot studies in order to test theoretical and experimental predictions prior to large-scale application in the field. On the downside, these pilot studies may introduce additional strategic incentives for the involved decision makers that researchers and regulators need to be aware of.

Finally, experimental studies in this thesis have provided several results that point to empirical regularities, which, however, are not (yet) well understood from a theoretical perspective. Based on the empirical results at the macro level, the development of microfounded theory is desired to gain a more precise understanding of how the observed market outcomes evolve. For instance, Section 3.3 points to a systematically lower degree of tacit collusion under continuous time which however is in contrast to the few theoretical analyses that suggest more cooperative behavior. In this context, broadening the scope of methodological approaches may be beneficial to either conduct explorative studies which could provide further stylized facts to inform theory building or to test early explanatory theory hypotheses (see Section 3.1). For these purposes, agent-based simulation could serve as a natural extension to laboratory experiments and as a means to create more comprehensive testbeds for institutions (Duffy, 2006). In this vein, future work could build on previous simulation studies that have examined individual strategies in the context of tacit collusion (Midgley et al., 1997; Erev and Roth, 1998; Waltman and Kaymak, 2008) as well as the design of markets and institutions (Bichler et al., 2010; Block et al., 2010; Ketter et al., 2013).

Above and beyond the aforementioned limitations, the findings of this thesis point to themes that have received only little attention in the extant literature, but are believed to play a major role in ICT markets. In particular, it is shown that tacit collusion and anti-competitive coordination between competitors have a profound impact on market outcomes, above and beyond the exploitation of market power by a single dominant firm. More specifically, it is found that implicit cooperation among competitors may have important ramifications for competition in and across vertically related markets. As ICT markets become more mature and concentrated at the services layer, and at the same time firms become more integrated across the value chain, these issues are likely to be magnified (see A.T. Kearney, 2016, for a summary of recent market developments). Whereas the recent literature has provided important insights into market power and its consequences in these markets, analysis of behavioral effects and collusion incentives in these contexts are currently scarce (see Hossain et al., 2011, for a rare experimental analysis in the context of two-sided markets). As a result, it is for example well-known that market concentration cannot be equated with market power per se in two-sided markets (Evans and Schmalensee, 2013), but whether such market concentration may facilitate coordinated behavior to the detriment of competitors, suppliers or consumers is currently unknown and thus open for future research.

Strategic decisions with regard to competition and cooperation as well as the balance of those activities will represent key challenges for firms across the ICT value chain (Nalebuff and Brandenburger, 1997; Bengtsson and Kock, 2000, 2014). In particular, firms will need to weigh short and long-term consequences of cooperative vertical relationships with respect to effects on horizontal competition in their respective markets. Moreover, competition will regularly take place between ecosystems, i.e., integrated organizations, or partnerships that exceed clearly delineated market boundaries and vertical value chain layers. Therefore, the management of access relationships and the optimal degree of openness are crucial strategic variables for firms' success in these markets (Eisenmann et al., 2008). As shown in this thesis and in line with previous studies, short-term benefits of cooperation may incentivize partnerships that prove to hurt some firms in the long-term (Mantovani and Ruiz-Aliseda, 2015). From a policy perspective, this points to new forms of market failures with regard to Open Access among competitors. In contrast to telecommunications infrastructure markets, where exclusion was the traditional concern, here, negative consequences on competition may result from voluntary or discriminatory access agreements. In the spirit of this thesis, policy proposals should thus be informed by microfounded theory and be subject to empirical examination in the designated context of application prior to implementation in the field.

# Appendix A

# Theoretical Analyses

## A.1 Oligopoly competition

Let the relevant industry consist of $n \in \mathbb{N}$ firms. Each firm produces one good and goods between firms are differentiated. Considering the representative consumer's utility function suggested by Singh and Vives (1984) and extending the generalization by Häckner (2000), inverse demand for firm $k \in \{1, ..., n\}$ is given by

$$p_k = \omega_k - \lambda_k q_k - \gamma \sum_{j \neq k} q_j$$

with $\omega_k, \lambda_k > 0, \forall k \in \{1, ..., n\}$ and the degree of substitutability $\gamma$. If $\gamma < 0$ goods are complementary, if $\gamma = 0$ goods are independent of one another, and if $\gamma > 0$ they are substitutes. $\omega_k$ may be interpreted as quality and thus, differences among firms as vertical differentiation. With substitute goods, $\omega_k$ is also firm $k$'s reservation price. $\lambda_k$ is the elasticity of inverse demand of firm $k$'s good. For simplicity, assume that $\lambda_k =$

$\lambda, \forall k \in \{1,...,n\}$ and let $\theta = \frac{\gamma}{\lambda}$. This bounds $\theta \leq 1$ with goods being perfect substitutes if $\theta = 1$. The inverse demand for firm $k$ then transforms to

$$p_k = \omega_k - \lambda \left( q_k + \theta \sum_{j \neq k} q_j \right). \tag{A.1}$$

Note that firms are vertically differentiated, i.e., asymmetric, and that symmetry requires $\omega_k = \omega, \forall k \in \{1,...,n\}$. To calculate the demand for firm $k$, summarize Equation (A.1) over all $n$ firms, which results in

$$\sum_{k=1}^{n} p_k = \sum_{k=1}^{n} \omega_k - \lambda \left( \sum_{k=1}^{n} q_k + \theta(n-1) \sum_{k=1}^{n} q_k \right)$$

using $\sum_{k=1}^{n} \sum_{j \neq k} q_j = (n-1) \sum_{k=1}^{n} q_k$. Solving this for $\sum_{k=1}^{n} q_k$ yields

$$\sum_{k=1}^{n} q_k = \frac{1}{\lambda(1+\theta(n-1))} \sum_{k=1}^{n} (\omega_k - p_k).$$

As a transformation of this equation, noting that

$$\begin{aligned} \sum_{k=1}^{n} q_k &= q_k + \sum_{j \neq k} q_j, \\ \sum_{k=1}^{n} \omega_k &= \omega_k + \sum_{j \neq k} \omega_j, \end{aligned} \tag{A.2}$$

and using Equation (A.1), firm $k$'s demand for non-perfect substitutes ($\theta < 1$) is given by

$$q_k = \frac{(\omega_k - p_k)(1+\theta(n-2)) - \theta \sum_{j \neq k} (\omega_j - p_j)}{\lambda(1-\theta)(1+\theta(n-1))} \tag{A.3}$$

provided that the quantity is non-negative and with $n$ as the number of firms with non-negative demand. Otherwise, if $q_k < 0$, firm $k$ exits the market and its demand is zero.

With costs normalized to zero and $q_{-k} = \{q_1, ..., q_n\} \setminus q_k$, firm $k$'s profit is given by $\Pi_k = p_k q_k$ with price $p_k(q_k, q_{-k})$ as a function of quantities in Cournot competition and quantity $q_k(p_k, p_{-k})$ as a function of prices in Bertrand competition. In the following analysis of Walrasian, Nash, and collusive equilibrium prices, quantities, and profits, subscripts are used to differentiate between Bertrand and Cournot competition.

**Walrasian equilibrium** In the Walrasian equilibrium, also referred to as competitive equilibrium, firms are assumed to have no market power and hence, are price-takers with all prices at marginal cost. Therefore, the Walrasian equilibrium is identical under Bertrand and Cournot competition. Setting Equation (A.1) to marginal cost, i.e., zero, it can be transformed to

$$q_k(q_{-k}) = \frac{\omega_k - \lambda\theta \sum_{j \neq k} q_j}{\lambda}.$$

Summing over all $n$ firms gives

$$\sum_{k=1}^{n} q_k = \frac{\sum_{k=1}^{n} \omega_k - \lambda\theta(n-1) \sum_{k=1}^{n} q_k}{\lambda},$$

which, using the previous Equation together with Equation (A.2), yields the Walrasian equilibrium

$$\begin{aligned} q_k^{Walras} &= \frac{\omega_k(1+\theta(n-2)) - \theta \sum_{j \neq k} \omega_j}{\lambda(1-\theta)(1+\theta(n-1))}, \\ p_k^{Walras} &= 0, \\ \Pi_k^{Walras} &= 0. \end{aligned} \tag{A.4}$$

**Nash equilibrium** In the Nash equilibrium under Cournot competition firm $k$ maximizes $\Pi_k$ with respect to its quantity $q_k$ given the other firms' quantities $q_{-k}$. Firm $k$'s best response is given by

$$q_k(q_{-k}) = \frac{\omega_k - \lambda\theta \sum_{j \neq k} q_j}{2\lambda}$$

and its sum over all $n$ firms amounts to

$$\sum_{k=1}^{n} q_k = \frac{\sum_{k=1}^{n} \omega_k - \lambda\theta(n-1)\sum_{k=1}^{n} q_k}{2\lambda}.$$

Using the previous Equation together with Equation (A.2), the Cournot Nash equilibrium can be retrieved as

$$\text{(A.5)} \qquad \begin{aligned} q_{Cournot,k}^{Nash} &= \frac{\omega_k(2+\theta(n-2)) - \theta\sum_{j\neq k}\omega_j}{\lambda(2-\theta)(2+\theta(n-1))}, \\ p_{Cournot,k}^{Nash} &= \frac{\omega_k(2+\theta(n-2)) - \theta\sum_{j\neq k}\omega_j}{(2-\theta)(2+\theta(n-1))}, \\ \Pi_{Cournot,k}^{Nash} &= \frac{(\omega_k(2+\theta(n-2)) - \theta\sum_{j\neq k}\omega_j)^2}{\lambda(2-\theta)^2(2+\theta(n-1))^2}. \end{aligned}$$

In the Nash equilibrium under Bertrand competition firm $k$ maximizes $\Pi_k$ with respect to its price $p_k$ given the other firms' prices $p_{-k}$. Firm $k$'s response function can be calculated as

$$p_k(p_{-k}) = \frac{\omega_k}{2} - \frac{\theta\sum_{j\neq k}(\omega_j - p_j)}{2(1+\theta(n-2))}.$$

Summing over all $n$ firms yields

$$\sum_{k=1}^{n} p_k = \frac{\sum_{k=1}^{n}\omega_k}{2} - \frac{\theta(n-1)\sum_{k=1}^{n}(\omega_k - p_k)}{2(1+\theta(n-2))},$$

which can be transformed using the previous Equation together with Equation (A.2) to retrieve the Bertrand Nash equilibrium

(A.6)

$$\begin{aligned} q_{Bertrand,k}^{Nash} &= \frac{(1+\theta(n-2))(\omega_k(\theta^2(n^2-5n+5)+3\theta(n-2)+2) - \theta(1+\theta(n-2))\sum_{j\neq k}\omega_j)}{\lambda(1-\theta)(1+\theta(n-1))(2+\theta(n-3))(2+\theta(2n-3))}, \\ p_{Bertrand,k}^{Nash} &= \frac{\omega_k(\theta^2(n^2-5n+5)+3\theta(n-2)+2) - \theta(1+\theta(n-2))\sum_{j\neq k}\omega_j}{(1+\theta(n-1))(2+\theta(n-3))(2+\theta(2n-3))}, \\ \Pi_{Bertrand,k}^{Nash} &= \frac{(1+\theta(n-2))(\omega_k(\theta^2(n^2-5n+5)+3\theta(n-2)+2) - \theta(1+\theta(n-2))\sum_{j\neq k}\omega_j)^2}{\lambda(1-\theta)(1+\theta(n-1))^2(2+\theta(n-3))^2(2+\theta(2n-3))^2}. \end{aligned}$$

As Häckner (2000) shows, Nash prices are always higher under Cournot competition than under Bertrand competition for substitute goods ($\theta > 0$). Instead, if goods are complements ($\theta < 0$) and vertical differentiation between firms is high, Nash prices of low-quality firms may be higher under Bertrand competition than under Cournot competition. With respect to profits there are different nuances. For complementary goods, Nash profits are always higher under Bertrand competition than under Cournot competition. Instead, if goods are substitutes, the opposite holds unless vertical differentiation between firms is low, when Nash profits of high-quality firms may be higher under Bertrand competition than under Cournot competition.

**Collusive equilibrium** In the collusive equilibrium firms employ JPM, i.e., firms behave like a single monopolist and maximize $\sum_{k=1}^{n} \Pi_k$. Therefore, the collusive equilibrium is identical under Bertrand and Cournot competition. Using Equation (A.1) and summing over the corresponding profit functions, joint profit of all $n$ firms is given by

$$\sum_{k=1}^{n} \Pi_k = \sum_{k=1}^{n} (\omega_k q_k) - \lambda \sum_{k=1}^{n} q_k^2 - \lambda\theta \sum_{k=1}^{n} (q_k \sum_{j \neq k} q_j).$$

Noting that $\frac{\partial \sum_{k=1}^{n} (q_k \sum_{j \neq k} q_j)}{\partial q_k} = 2 \sum_{j \neq k} q_j$, the first-order condition of JPM can be calculated as

$$q_k(q_{-k}) = \frac{\omega_k - 2\lambda\theta \sum_{j \neq k} q_j}{2\lambda}.$$

Again summing over all $n$ firms results in

$$\sum_{k=1}^{n} q_k = \frac{\sum_{k=1}^{n} \omega_k}{2\lambda} - \theta(n-1) \sum_{k=1}^{n} q_k,$$

which finally yields the collusive equilibrium using the previous Equation and Equation (A.2) as

$$
\begin{aligned}
q^{JPM} &= \frac{\omega_k(1+\theta(n-2)) - \theta \sum_{j\neq k} \omega_j}{2\lambda(1-\theta)(1+\theta(n-1))}, \\
p^{JPM} &= \frac{\omega_k}{2}, \\
\Pi^{JPM} &= \frac{\omega_k(\omega_k(1+\theta(n-2)) - \theta \sum_{j\neq i} \omega_j)}{4\lambda(1-\theta)(1+\theta(n-1))}.
\end{aligned} \tag{A.7}
$$

Note that JPM prices are linearly connected to vertical differentiation as firm $k$'s price in collusive equilibrium depends solely on its own quality.

**Symmetric firms** In case of symmetric firms without vertical product differentiation, i.e., $\omega_k = \omega, \forall k \in \{1, ..., N\}$, $k$'s demand function, i.e., Equation (A.3), simplifies to

$$
\begin{aligned}
q_k &= \frac{(\omega - p_k)(1+\theta(n-2)) - \theta \sum_{j\neq k}(\omega - p_j)}{\lambda(1-\theta)(1+\theta(n-1))} \\
&= \underbrace{\frac{\omega}{\lambda(1+\theta(n-1))}}_{\Gamma} - \underbrace{\frac{1+\theta(n-2)}{\lambda(1-\theta)(1+\theta(n-1))}}_{\Lambda} p_k + \underbrace{\frac{\theta(n-1)}{\lambda(1-\theta)(1+\theta(n-1))}}_{\Theta} \frac{\sum_{j\neq k} q_j}{n-1} \\
&= \Gamma - \Lambda p_k + \Theta \frac{\sum_{j\neq k} q_j}{n-1}
\end{aligned}
$$

with $\Gamma, \Lambda, \Theta > 0$ for substitute goods ($\theta > 0$). Consequently, the Walrasian equilibrium given by Equation (A.4), which predicts marginal cost pricing, simplifies to

$$
\begin{aligned}
q^{Walras} &= \frac{\omega}{\lambda(1+\theta(n-1))}, \\
p^{Walras} &= 0, \\
\Pi^{Walras} &= 0.
\end{aligned}
$$

In the Nash equilibrium under Cournot competition firm $k$ maximizes $\Pi_k$ with respect to $q_k$. With symmetric firms, Equation (A.5) yields the Cournot Nash equilibrium

$$\begin{aligned} q_{Cournot}^{Nash} &= \frac{\omega}{\lambda(2+\theta(n-1))}, \\ p_{Cournot}^{Nash} &= \frac{\omega}{2+\theta(n-1)}, \\ \Pi_{Cournot}^{Nash} &= \frac{\omega^2}{\lambda(2+\theta(n-1))^2}. \end{aligned}$$

In the Nash equilibrium under Bertrand competition firm $k$ maximizes $\Pi_k$ with respect to $p_k$. With symmetric firms and Equation (A.6), the Bertrand Nash equilibrium is given by

$$\begin{aligned} q_{Bertrand}^{Nash} &= \frac{\omega(1+\theta(n-2))}{\lambda(2+\theta(n-3))(1+\theta(n-1))}, \\ p_{Bertrand}^{Nash} &= \frac{\omega(1-\theta)}{2+\theta(n-3)}, \\ \Pi_{Bertrand}^{Nash} &= \frac{\omega^2(1-\theta)(1+\theta(n-2))}{\lambda(2+\theta(n-3))^2(1+\theta(n-1))}. \end{aligned}$$

Finally, in the collusive equilibrium, with firms employing JPM and irrespective of Bertrand or Cournot competition, Equation (A.7) simplifies to

$$\begin{aligned} q^{JPM} &= \frac{\omega}{2\lambda(1+\theta(n-1))}, \\ p^{JPM} &= \frac{\omega}{2}, \\ \Pi^{JPM} &= \frac{\omega^2}{4\lambda(1+\theta(n-1))}. \end{aligned}$$

## Parameterized and scaled theoretical benchmarks

TABLE A.1: *Scaled theoretical benchmarks of oligopoly competition for each treatment with symmetric firm as displayed in the experiment.*

| | Bertrand | Cournot |
|---|---|---|
| Duopoly | $p^{Walras} = 0$ | $p^{Walras} = 0$ |
| | $q^{Walras} = 60.00$ | $q^{Walras} = 100.00$ |
| | $\Pi^{Walras} = 0$ | $\Pi^{Walras} = 0$ |
| | $p^{Nash} = 25.00$ | $p^{Nash} = 37.50$ |
| | $q^{Nash} = 45.00$ | $q^{Nash} = 62.50$ |
| | $\Pi^{Nash} = 1406.25$ | $\Pi^{Nash} = 1406.25$ |
| | $p^{JPM} = 50.00$ | $p^{JPM} = 50.00$ |
| | $q^{JPM} = 30.00$ | $q^{JPM} = 50.00$ |
| | $\Pi^{JPM} = 1875.00$ | $\Pi^{JPM} = 1500.00$ |
| Triopoly | $p^{Walras} = 0$ | $p^{Walras} = 0$ |
| | $q^{Walras} = 42.86$ | $q^{Walras} = 100.00$ |
| | $\Pi^{Walras} = 0$ | $\Pi^{Walras} = 0$ |
| | $p^{Nash} = 16.67$ | $p^{Nash} = 30.00$ |
| | $q^{Nash} = 35.71$ | $q^{Nash} = 70.00$ |
| | $\Pi^{Nash} = 1406.25$ | $\Pi^{Nash} = 1406.25$ |
| | $p^{JPM} = 50.00$ | $p^{JPM} = 50.00$ |
| | $q^{JPM} = 21.43$ | $q^{JPM} = 50.00$ |
| | $\Pi^{JPM} = 2531.42$ | $\Pi^{JPM} = 1674.22$ |
| Quadropoly | $p^{Walras} = 0$ | $p^{Walras} = 0$ |
| | $q^{Walras} = 33.33$ | $q^{Walras} = 100.00$ |
| | $\Pi^{Walras} = 0$ | $\Pi^{Walras} = 0$ |
| | $p^{Nash} = 12.50$ | $p^{Nash} = 25.00$ |
| | $q^{Nash} = 29.17$ | $q^{Nash} = 75.00$ |
| | $\Pi^{Nash} = 1406.25$ | $\Pi^{Nash} = 1406.25$ |
| | $p^{JPM} = 50.00$ | $p^{JPM} = 50.00$ |
| | $q^{JPM} = 16.67$ | $q^{JPM} = 50.00$ |
| | $\Pi^{JPM} = 3214.29$ | $\Pi^{JPM} = 1875.00$ |

TABLE A.2: *Scaled theoretical benchmarks of oligopoly competition for the asymmetric Bertrand treatments as displayed in the experiment.*

| | Incumbent | Entrant |
|---|---|---|
| Triopoly | $p^{Walras} = 0$ | $p^{Walras} = 0$ |
| | $q^{Walras} = 55.92$ | $q^{Walras} = 37.63$ |
| | $\Pi^{Walras} = 0$ | $\Pi^{Walras} = 0$ |
| | $p^{Nash} = 18.26$ | $p^{Nash} = 15.82$ |
| | $q^{Nash} = 41.52$ | $q^{Nash} = 33.90$ |
| | $\Pi^{Nash} = 2109.38$ | $\Pi^{Nash} = 1406.25$ |
| | $p^{JPM} = 50.00$ | $p^{JPM} = 50.00$ |
| | $q^{JPM} = 27.96$ | $q^{JPM} = 18.82$ |
| | $\Pi^{JPM} = 4897.86$ | $\Pi^{JPM} = 3166.26$ |
| Quadropoly | $p^{Walras} = 0$ | $p^{Walras} = 0$ |
| | $q^{Walras} = 44.50$ | $q^{Walras} = 30.14$ |
| | $\Pi^{Walras} = 0$ | $\Pi^{Walras} = 0$ |
| | $p^{Nash} = 14.00$ | $p^{Nash} = 11.98$ |
| | $q^{Nash} = 34.23$ | $q^{Nash} = 27.95$ |
| | $\Pi^{Nash} = 2109.38$ | $\Pi^{Nash} = 1406.25$ |
| | $p^{JPM} = 50.00$ | $p^{JPM} = 50.00$ |
| | $q^{JPM} = 22.25$ | $q^{JPM} = 15.07$ |
| | $\Pi^{JPM} = 3889.00$ | $\Pi^{JPM} = 2466.92$ |

TABLE A.3: *Nash predictions $p^{Nash}$ as measured by Walrasian-based degree of tacit collusion $\varphi^{Walras}$ under asymmetric Bertrand competition controlling for scaling in each treatment.*

| | Incumbent | Entrant |
|---|---|---|
| Triopoly | 0.37 | 0.32 |
| Quadropoly | 0.28 | 0.24 |

## A.2 Margin squeeze regulation

Retail demand for firm $k \in \{A, B, D\}$ in case of $n = 3$ active firms according to Shubik and Levitan (1980) is given by

$$q_k^{Triopoly} = \frac{1}{3} \cdot (1 - p_k - \gamma \cdot (p_k - \frac{p_A + p_B + p_D}{3}).$$

Assume w.l.o.g. that Firm A is the single wholesale access provider to the retailer Firm D. Firms' profits are then given by

$$\begin{aligned}
\pi_A &= p_A \cdot q_A(p_A, p_B, p_D) + a \cdot q_D(p_A, p_B, p_D), \\
\pi_B &= p_B \cdot q_B(p_A, p_B, p_D), \\
\pi_D &= (p_D - a) \cdot q_D(p_A, p_B, p_D).
\end{aligned}$$

**Three-stage model with a competitive fringe** The subgame-perfect Nash equilibria are determined through backward induction. Under NR, in Stage 3, Firm D's first order condition $\frac{\partial \pi_D}{\partial p_D} = 0$ yields its best response $p_D^{NR} = \frac{1}{2} \frac{2a\gamma + \gamma p_A + \gamma p_B + 3a + 3}{3 + 2\gamma}$ given integrated firms' prices. In Stage 2, integrated firms $i \in \{A, B\}$ solve $\frac{\partial \pi_i(p_D^{NR})}{\partial p_i} = 0$ simultaneously, thus yielding

$$\begin{aligned}
p_A^{NR} &= \frac{22a\gamma^4 + 101a\gamma^3 + 150a\gamma^2 + 95\gamma^3 + 72a\gamma + 384\gamma^2 + 504\gamma + 216}{57\gamma^4 + 428\gamma^3 + 1092\gamma^2 + 1152\gamma + 432}, \\
p_B^{NR} &= \frac{16a\gamma^4 + 64a\gamma^3 + 84a\gamma^2 + 95\gamma^3 + 36a\gamma + 384\gamma^2 + 504\gamma + 216}{57\gamma^4 + 428\gamma^3 + 1092\gamma^2 + 1152\gamma + 432}.
\end{aligned}$$

In Stage 1, Firm A chooses the wholesale price $a^{NR}$ anticipating its competitors' best responses, i.e., according to $\frac{\partial \pi_A(p_A^{NR}, p_B^{NR}, p_D^{NR})}{\partial a} = 0$, which yields

$$a^{NR} = \frac{4\left(49\gamma^4 + 336\gamma^3 + 828\gamma^2 + 864\gamma + 324\right)\left(19\gamma^2 + 54\gamma + 36\right)}{973\gamma^7 + 17071\gamma^6 + 111816\gamma^5 + 370476\gamma^4 + 686880\gamma^3 + 723168\gamma^2 + 404352\gamma + 93312}.$$

Simple plugging in of equilibrium prices gives equilibrium retail demands and equilibrium profits dependent on $\gamma$. For the sake of brevity, the algebraic expressions are not denoted here, but can be found in the online appendix. Testing for the margin squeeze condition

$$\begin{aligned}\Delta &= p_A^{NR} - a^{NR} \\ &= -\frac{\gamma^2\left(665\gamma^4 + 3543\gamma^3 + 6984\gamma^2 + 6048\gamma + 1944\right)}{973\gamma^7 + 17071\gamma^6 + 111816\gamma^5 + 370476\gamma^4 + 686880\gamma^3 + 723168\gamma^2 + 404352\gamma + 93312}\end{aligned}$$

shows that $\Delta < 0$ for $\gamma > 0$ and thus, Firm A engages in a margin squeeze if retail goods are substitutes. Despite that, Firm D is still active in the retail market with a positive demand

$$q_D^{NR} = \frac{1}{6}\frac{399\gamma^7 + 9893\gamma^6 + 67488\gamma^5 + 218268\gamma^4 + 388368\gamma^3 + 391392\gamma^2 + 209952\gamma + 46656}{973\gamma^7 + 17071\gamma^6 + 111816\gamma^5 + 370476\gamma^4 + 686880\gamma^3 + 723168\gamma^2 + 404352\gamma + 93312}$$

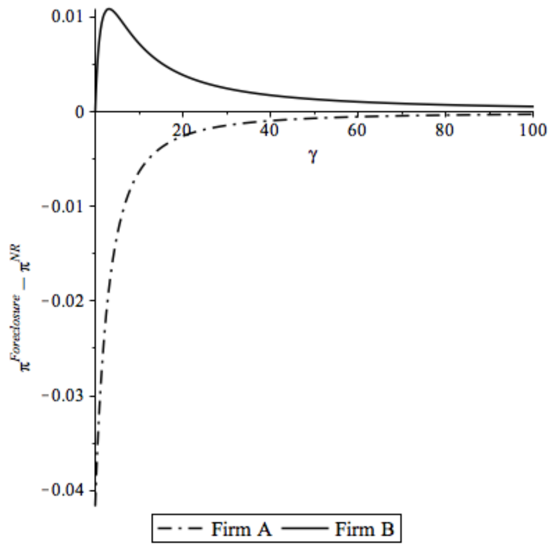
as Firm A does not find it profitable to foreclose its downstream competitor, which is shown in the following.

Foreclosure occurs if Firm A's wholesale price is so high compared to retail prices such that Firm D is unable to set a retail price that would yield a positive profit. Then, Firm D does not supply any retail consumers and a retail duopoly ensues with

$$q_i^{Foreclosure} = \frac{1+\gamma}{3}(1 - p_i - \frac{\gamma}{(3+2\gamma)}(2 - (p_A + p_B))$$

as integrated firm $i$'s retail demand (Höffler, 2008). Profit-maximization of integrated firms in case of foreclosure yields equilibrium profits $\pi_i^{Foreclosure}(\gamma)$. Figure A.1 depicts the difference of equilibrium profits $\pi_i^{Foreclosure} - \pi_i^{NR}$ for both integrated firms. Irrespective of the degree of differentiation, for substitute goods, i.e., $\gamma > 0$, Firm B seeks foreclosure due to higher downstream profits, but Firm A does not. Instead, the Firm A benefits from a viable wholesale offer to Firm D and thus has no incentive to foreclose its competitor even in the absence of regulation.

FIGURE A.1: *Comparison of profits in the case of (non-)foreclosure under NR.*




Under MSR, in Stage 2, Firm A is constrained in its retail price setting by the requirement that $\Delta \geq 0$. Because it prefers to engage in a margin squeeze under NR, the margin squeeze condition is binding and $p_A^{MSR} = a^{MSR}$. Firm B's corresponding retail price is $p_B^{MSR} = \frac{1}{2}\frac{7a\gamma^2+9a\gamma+15\gamma+18}{7\gamma^2+24\gamma+18}$. In Stage 1, Firm A sets $a^{MSR} = \frac{3}{2}\frac{19\gamma^2+54\gamma+36}{7\gamma^3+81\gamma^2+180\gamma+108}$. Again, equilibrium retail demands and equilibrium profits can be obtained by simple computations.

**Two-stage model with simultaneous retail pricing** The initial three-stage game is reduced to a two-stage game in which all three firms choose retail prices simultaneously. Under NR, if Firm A makes a viable wholesale offer in Stage 1, in Stage 2 firms choose retail prices

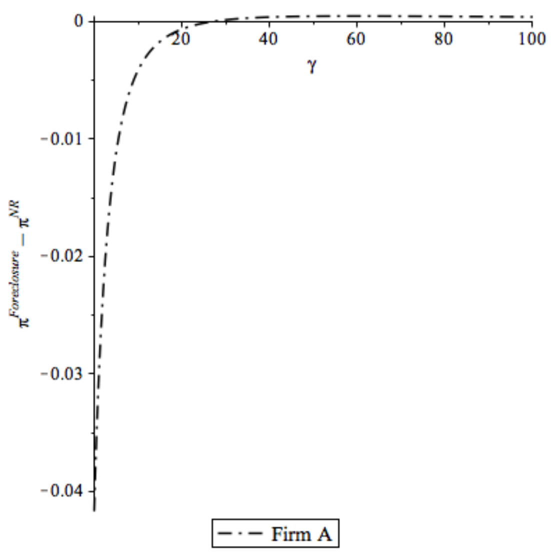
$$p_A^{NR} = \frac{1}{2}\frac{5a\gamma^2 + 9a\gamma + 15\gamma + 18}{5\gamma^2 + 21\gamma + 18},$$
$$p_B^{NR} = \frac{3}{2}\frac{a\gamma^2 + a\gamma + 5\gamma + 6}{5\gamma^2 + 21\gamma + 18},$$
$$p_D^{NR} = \frac{1}{2}\frac{7a\gamma^2 + 21a\gamma + 18a + 15\gamma + 18}{5\gamma^2 + 21\gamma + 18}.$$

Anticipating these retail prices, Firm A chooses the profit-maximizing wholesale price

$$a^{NR} = \frac{3(25\gamma^3 + 120\gamma^2 + 198\gamma + 108)}{20\gamma^4 + 249\gamma^3 + 909\gamma^2 + 1296\gamma + 648}.$$

If instead, Firm A does not make a viable wholesale offer but decides to foreclose Firm D, integrated firms' profits are given by $\pi_i^{Foreclosure}(\gamma)$ as obtained for the previous three-stage model. Solving $\pi_A^{Foreclosure} > \pi_A^{NR}$ for the degree of substitutability yields $\gamma > 26.77 =: \overline{\gamma}$, i.e., Firm A benefits from foreclosure if retail goods are close substitutes (see Figure A.2). Therefore, as noted by Atiyas et al. (2015) and Bourreau et al. (2011), foreclosure is the unique equilibrium outcome for $\gamma > \overline{\gamma}$. Otherwise, Firm A makes a viable wholesale offer and all three firms participate in the downstream market in equilibrium.

FIGURE A.2: *Comparison of Firm A's profit in the case of (non-)foreclosure under NR.*




While in case of foreclosure Firm A's price structure clearly violates the margin squeeze constraint, an additional analysis is warranted for $\gamma \leq \overline{\gamma}$. Testing for the margin squeeze condition

$$\Delta = p_A^{NR} - a^{NR} = -\frac{3}{2}\frac{\gamma\left(5\gamma^2 - 9\gamma - 18\right)}{20\gamma^4 + 249\gamma^3 + 909\gamma^2 + 1296\gamma + 648}$$

demonstrates that $\Delta < 0$ for $\gamma > 3$ so that only for strongly differentiated goods, i.e., $\gamma \in [0,3]$, the margin squeeze condition is not binding. Therefore, under MSR, in Stage 2 Firm A sets $p_A^{MSR} = a^{MSR}$ for all $\gamma > 3$. The competitors' prices for $\gamma \in (3, \overline{\gamma})$ are given by

$$p_B^{MSR} = \frac{1}{3} \frac{7a\gamma^2 + 9a\gamma + 15\gamma + 18}{5\gamma^2 + 16\gamma + 12},$$
$$p_D^{MSR} = \frac{1}{3} \frac{13a\gamma^2 + 30a\gamma + 18a + 15\gamma + 18}{5\gamma^2 + 16\gamma + 12}.$$

In Stage 1, Firm A anticipates these decisions and sets the wholesale price $a^{MSR} = \frac{3}{4} \frac{5\gamma+6}{\gamma^2+9\gamma+9}$.

**Two-stage model with simultaneous retail quantity competition** In order to examine the effect of MSR in case of retail quantity competition, a two-stage game that is similar to the one detailed above is considered with the exception that firms choose quantities in Stage 2 and compete according to the demand structure suggested by Singh and Vives (1984). Following the generalization by Häckner (2000) for more than two firms, inverse retail demand of firm $k \in \{A, B, D\}$ in the case of symmetric competitors is given by

$$p_k = \omega - \lambda \left( q_k + \theta \sum_{j \neq k} q_j \right)$$

with $\omega, \lambda > 0$ and $\theta$ as a standardized measure of substitutability (see Appendix A.1). Here only the case of $\theta \in [0,1]$ is considered. For ease of illustration, let $\omega = 100$ and $\lambda = 1$.

Under NR, in Stage 2, firms simultaneously choose

$$q_i^{NR} = -\frac{1}{2} \frac{a\theta - 100\theta + 200}{\theta^2 - \theta - 2},$$
$$q_D^{NR} = \frac{1}{2} \frac{a\theta + 2a + 100\theta - 200}{\theta^2 - \theta - 2},$$

where $i \in \{A, B\}$. In Stage 1, Firm A anticipates these decisions and sets

$$a^{NR} = -\frac{100(\theta^3 - 4\theta^2 + 2\theta + 4)}{2\theta^3 + 3\theta^2 - 8\theta - 8}.$$

In order to identify whether Firm A engages in a margin squeeze, Firm A's retail price $p_A^{NR}$ that arises from all firms' quantity decisions is calculated and then

$$\Delta = p_A^{NR} - a^{NR} = \frac{50\theta\left(2\theta^2 - 5\theta + 2\right)}{2\theta^3 + 3\theta^2 - 8\theta - 8}$$

is determined to test the margin squeeze condition, for which $\Delta < 0$ if $\theta \in (0, 0.5)$. Therefore, Firm A engages in a margin squeeze for rather differentiated goods.

Plugging in equilibrium quantities and the optimal wholesale price yields equilibrium profits $\pi_k^{NR}$, which are now compared to the case of foreclosure which ensues profits $\pi_i^{Foreclosure}(\theta)$. Provided that Firm D is foreclosed, the integrated firms choose $q_i^{Foreclosure} = \frac{100}{\theta+2}$. Comparing profits between foreclosure and non-foreclosure for both integrated firms yields

$$\begin{aligned}
\pi_A^{Foreclosure} - \pi_A^{NR} &= \frac{2500(\theta^4 + 4\theta^3 - 4\theta^2 - 16\theta + 16)}{(\theta + 2)^2\,(2\theta^3 + 3\theta^2 - 8\theta - 8)}, \\
\pi_B^{Foreclosure} - \pi_B^{NR} &= \frac{2500\theta\left(7\theta^5 + 24\theta^4 - 36\theta^3 - 128\theta^2 + 48\theta + 128\right)}{(\theta + 2)^2\,(2\theta^3 + 3\theta^2 - 8\theta - 8)^2},
\end{aligned}$$

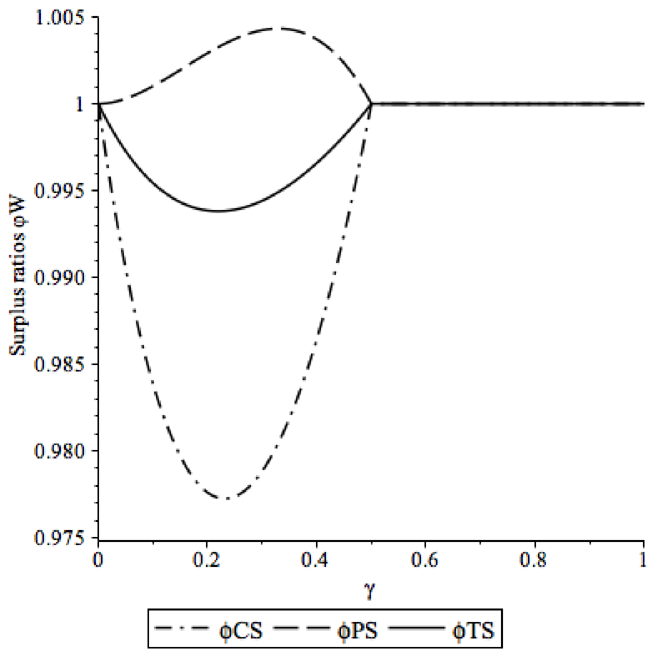
where $\pi_A^{Foreclosure} - \pi_A^{NR} < 0$ and $\pi_B^{Foreclosure} - \pi_B^{NR} > 0$ for all $\theta \in [0, 1]$. Hence, in analogy to the two-stage price competition model, Firm B prefers foreclosure, whereas Firm A benefits from making Firm D a viable wholesale offer.

Under MSR, in Stage 2, constrained pricing of Firm A and simultaneous profit maximization by its competitors yields retail quantities

$$q_A^{MSR} = \frac{2(a + 50\theta - 100)}{2\theta^2 - \theta - 2},$$
$$q_B^{MSR} = -\frac{2a\theta^2 - 3a\theta - 100\theta^2 + 300\theta - 200}{(\theta - 2)(2\theta^2 - \theta - 2)},$$
$$q_D^{MSR} = \frac{2(a\theta + 50\theta^2 - a - 150\theta + 100)}{(\theta - 2)(2\theta^2 - \theta - 2)}.$$

In Stage 1, Firm A sets $a^{MSR} = -25\theta + 50$. Ensuing prices and profits allow to compute consumer surplus, producer surplus, and total surplus as in the main analysis. Figure A.3 depicts the effect of MSR relative to NR for these welfare measures. The implications are similar to the investigated three-stage price competition model: while MSR is to consumers' detriment, producers benefit from it. Because the former effect outweighs the latter, total surplus is unambiguously lower under MSR than NR.

FIGURE A.3: *MSR effect on consumer surplus, producer surplus, and total surplus.*



## A.3 Wholesale competition

The market structure and retail demand is identical to the previous analysis of infrastructure competition under margin squeeze regulation in Appendix A.2. Thus, retail demand in the case of $n = 3$ active firms is given by

$$q_k^{Triopoly} = \frac{1}{3} \cdot (1 - p_k - \gamma \cdot (p_k - \frac{p_A + p_B + p_D}{3}),$$

and in the case for foreclosure ($n = 2$) by:

$$q_k^{Foreclosure} = \frac{1+\gamma}{3} \cdot (1 - p_k - \frac{\gamma}{(3+2\gamma)} \cdot (2 - (p_A + p_B)).$$

In the following, let $\gamma = 30$. Assume w.l.o.g. that Firm A provides wholesale access to the retailer Firm D. This yields profits

$$\pi_A = p_A \cdot q_A(p_A, p_B, p_D) + a \cdot q_D(p_A, p_B, p_D),$$
$$\pi_B = p_B \cdot q_B(p_A, p_B, p_D),$$
$$\pi_D = (p_D - a) \cdot q_D(p_A, p_B, p_D).$$

In the following, Nash predictions are calculated for the market scenarios: (i) wholesale monopoly under no regulation, (ii) wholesale monopoly under margin squeeze regulation, (iii) wholesale competition under no regulation, and (iv) wholesale competition under margin squeeze regulation, each for all four timing models as described in Subsection 5.2.1. For the sequential-move Timing Models (1), (2), and (4) subgame-perfect Nash equilibria are determined through backward induction. In order to facilitate the comparison of theoretical predictions and experimental results, final prices and profits are scaled as in the experiment. Note that scaling affects only the output, but calculations are based on the original Shubik and Levitan (1980) values. Price (profit) values are multiplied by factor $\theta = {}^{100}/_{0.15}$ ($\Theta = 400$) to obtain scaled values.

**Timing Model (1):** Under a wholesale monopoly, in stage II, two (integrated) or three firms may operate in the retail market depending on the wholesale price chosen in stage I. In stage II, in case of foreclosure, i.e., $q_D = 0$, integrated firms' profit-maximizing prices are given by $p_A^{Foreclosure} = p_B^{Foreclosure} = 55.5\overline{5}$ and profits amount to $\pi_A^{Foreclosure} = \pi_B^{Foreclosure} = 15.04$. Instead, in case there is a viable wholesale offer, firms choose retail prices $p_A^{Triopoly} = \theta(\frac{1}{22} + \frac{265}{572}a)$, $p_B^{Triopoly} = \theta(\frac{1}{22} + \frac{155}{572}a)$, and $p_D^{Triopoly} = \theta(\frac{1}{22} + \frac{193}{286}a)$. In stage I, anticipating retail prices, Firm A chooses the monopolistic wholesale price $a^{Triopoly} = 66.36$. Ensuing retail prices are given by $p_A^{Triopoly} = 61.05$, $p_B^{Triopoly} = 48.29$, and $p_D^{Triopoly} = 75.08$ and profits by $\pi_A^{Triopoly} = 14.97$, $\pi_B^{Triopoly} = 14.69$, and $\pi_D^{Triopoly} = 0.48$. Comparing $\pi_A^{Foreclosure}$ to $\pi_A^{Triopoly}$, Firm A prefers the foreclosure outcome and thus sets a wholesale price $a^{Foreclosure} \in (93.19, 100]$, which forces the retailer to exit the retail market.

Taking into account margin squeeze regulation, foreclosure is ruled out as a valid market outcome and therefore does not constitute an equilibrium. However, as $a_A^{Triopoly} > p_A^{Triopoly}$, Firm A would violate the margin squeeze condition if it could set its prices freely. Instead, Firm A is required to maximize its profit $\pi_A$ subject to the condition $a_A \leq p_A$ in stage II, while the other firms maximize profits unconstrained. This yields $p_A^{MSR} = a$, $p_B^{MSR} = \theta(\frac{1}{32} + \frac{365}{832}a)$, and $p_D^{MSR} = \theta(\frac{1}{32} + \frac{701}{832}a)$. In stage I, Firm A sets the monopoly wholesale price to $a_A^{MSR} = 66.16$ and corresponding retail prices are given by $p_A^{MSR} = 66.16$, $p_B^{MSR} = 49.86$, and $p_D^{MSR} = 76.57$ with profits $\pi_A^{MSR} = 15.09$, $\pi_B^{MSR} = 15.66$, and $p_D^{MSR} = 0.68$.

Considering unregulated wholesale competition, two equilibria emerge, namely a competitive and a foreclosure type. Atiyas et al. (2015) show that for $\gamma > 26.77$ (and observable wholesale contracts) the foreclosure outcome constitutes an additional Nash

TABLE A.4: *Theoretical predictions for Timing Model (1).*

| | No regulation | | Margin squeeze regulation | |
|---|---|---|---|---|
| Wholesale monopoly | $a_A =$ | 100.00 | $a_A =$ | 66.19 |
| | $p_A =$ | 55.56 | $p_A =$ | 66.19 |
| | $p_B =$ | 55.56 | $p_B =$ | 49.86 |
| | $p_D =$ | 100.00 | $p_D =$ | 76.57 |
| Wholesale competition | $a_A = a_B =$ | 100.00 | $a_A = a_B =$ | 0.00 |
| | $p_A = p_B =$ | 55.56 | $p_A = p_B = p_D =$ | 30.30 |
| | $p_D =$ | 100.00 | | |
| | *or:* | | | |
| | $a_A = a_B =$ | 0.00 | | |
| | $p_A = p_B = p_D =$ | 30.30 | | |

equilibrium next to the competitive outcome. As shown for the case of a wholesale monopoly, an integrated firm does not find it profitable to deviate from the state of coordinated foreclosure in the wholesale market, because wholesale profits are outweighed by the retailer's business stealing effect in the retail market, even at the monopoly price. Moreover, given the nonviable wholesale offers, no firm $k$ has an incentive to deviate from its foreclosure price $p_k^{Foreclosure}$. In contrast, as shown by Bourreau et al. (2012b), if a firm is required to make a viable wholesale offer, integrated firms always find it profitable to undercut their rival in the wholesale market for $\gamma < 40.97$. Once wholesale prices are driven to zero, i.e., $a_A^{Competitive} = a_B^{Competitive} = 0$, firms cannot unilaterally increase the wholesale price profitably. Thus the competitive outcome $a_A^{Competitive} = a_B^{Competitive} = 0$ with ensuing retail prices $p_k^{Competitive} = 30.30$ and profits $\pi_k^{Competitive} = 5.79$, $\forall k \in \{A, B, D\}$, constitutes a Nash equilibrium.

Whereas in the case of no regulation two types of equilibria coexist, the competitive equilibrium is unique in the case of wholesale competition under margin squeeze regulation. Integrated firms are now unable to foreclose the retailer, due to the margin squeeze condition, while the Bertrand logic applies as described above for the unregulated case. These results are summarized in Table A.4.

**Timing Model (2):** In stage III, the retailer's optimal price as a follower is given by its best response function, i.e., $p_D = BR(p_A, p_B) = \theta(\frac{1}{42} + \frac{5}{21}p_A + \frac{5}{21}p_B + \frac{1}{2}a)$ across all scenarios. Anticipating the retailer's reaction, integrated firms' simultaneous (unconstrained) profit-maximization in stage II yields $p_A = \theta(\frac{13}{261} + \frac{5320}{15109}a)$ and $p_B = \theta(\frac{13}{261} + \frac{7595}{30218}a)$.

In the monopoly case, Firm A maximizes its profit by setting its wholesale price to $a_A = 67.39$ in stage I. Ensuing retail prices are given by $p_A^{Triopoly} = 56.94$, $p_B^{Triopoly} = 50.14$, and $p_D^{Triopoly} = 75.07$ and firms make profits $\pi_A^{Triopoly} = 15.61$, $\pi_B^{Triopoly} = 14.05$, and $\pi_D^{Triopoly} = 0.37$. Note that under this timing model $\pi_A^{Triopoly}$ exceeds the foreclosure profit $\pi_A^{Foreclosure}$, because Firm A internalizes the retailer's reaction to its own prices. Therefore, Firm A finds it always profitable to make a viable wholesale offer to Firm D.

Although foreclosure does not constitute an equilibrium under no regulation, Nash prices of Firm A still violate the margin squeeze condition. Taking into account this condition, constrained maximization of Firm A's profit in stage II yields prices $p_A^{MSR} = a_A$ and $p_B^{MSR} = \theta(\frac{13}{391} + \frac{365}{782}a)$. The optimal wholesale price in stage I is given by $a^{MSR} = 70.14$ and respective retail prices are $p_A^{MSR} = 70.14$, $p_B^{MSR} = 54.90$, $p_D^{MSR} = 80.72$. Firms' profits amount to $\pi_A^{MSR} = 16.24$, $\pi_B^{MSR} = 16.84$, and $\pi_D^{MSR} = 0.70$. Note that margin squeeze regulation leads to unambiguously higher prices and increased profits compared to the no regulation outcome, given this timing model.

In the case of wholesale competition, the Bertrand logic, as laid out in Timing Model (1), applies equally with regard to the integrated firms' behavior in stage I. Moreover, the competitive outcome is unique, because one of the integrated firms will always find it profitable to unilaterally deviate from coordinated foreclosure and supply the retailer.

TABLE A.5: *Theoretical predictions for Timing Model (2).*

| | No regulation | | Margin squeeze regulation | |
|---|---|---|---|---|
| Wholesale monopoly | $a_A =$ | 67.39 | $a_A =$ | 70.14 |
| | $p_A =$ | 56.94 | $p_A =$ | 70.14 |
| | $p_B =$ | 50.15 | $p_B =$ | 54.90 |
| | $p_D =$ | 75.07 | $p_D =$ | 80.72 |
| Wholesale competition | $a_A = a_B =$ | 0.00 | $a_A = a_B =$ | 0.00 |
| | $p_A = p_B = p_D =$ | 30.30 | $p_A = p_B = p_D =$ | 30.30 |

Given the theoretical prediction, margin squeeze regulation does not affect the market outcome under wholesale competition in Timing Model (2), because equilibrium prices in the unregulated outcome do not violate the margin squeeze constraint. See Table A.5 for a summary of results.

**Timing Model (3):** In the case of an unregulated monopolistic wholesale provider, simultaneous setting of all prices (wholesale and retail) leads to foreclosure as the unique equilibrium. Consider, in contrast, a situation in which Firm D makes positive profit, i.e., $a_A < p_D$. Obviously, Firm A can then increase its profit by setting $a_A = p_D$. However, Firm D would in turn increase its retail price $p_D$ as long as it is able to obtain a positive demand ($q_D > 0$). Consequently, this *reverse* Bertrand logic gives rise to foreclosure as the unique equilibrium.

In the case of margin squeeze regulation, Firm A solves $\frac{\partial \pi_A}{\partial p_A} = 0$ and $\frac{\partial \pi_A}{\partial a_A} = 0$ simultaneously subject to the constraint $a_A \leq p_A$, while Firm B and Firm D solve first order conditions $\frac{\partial \pi_B}{\partial p_B} = 0$ and $\frac{\partial \pi_D}{\partial p_D} = 0$. Optimal prices are given by $a_A^{MSR} = p_A^{MSR} = 67.61$, $p_B^{MSR} = 50.49$, and $p_D^{MSR} = 77.80$ leading to profits $\pi_A^{MSR} = 15.08$, $\pi_B^{MSR} = 16.06$, and $\pi_D^{MSR} = 0.65$.

If both integrated firms are active in the wholesale market, the same rationale as under Timing Model (1) applies, i.e., the competitive as well as the foreclosure outcome constitute an equilibrium. On the one hand, if both firms choose a wholesale price that

TABLE A.6: *Theoretical predictions for Timing Model (3).*

| | No regulation | | Margin squeeze regulation | |
|---|---|---|---|---|
| Wholesale monopoly | $a_A =$ | 100.00 | $a_A =$ | 67.61 |
| | $p_A =$ | 55.56 | $p_A =$ | 67.61 |
| | $p_B =$ | 55.56 | $p_B =$ | 50.49 |
| | $p_D =$ | 100.00 | $p_D =$ | 77.80 |
| Wholesale competition | $a_A = a_B =$ | 100.00 | $a_A = a_B =$ | 0.00 |
| | $p_A = p_B =$ | 55.56 | $p_A = p_B = p_D =$ | 30.30 |
| | $p_D =$ | 100.00 | | |
| | *or:* | | | |
| | $a_A = a_B =$ | 0.00 | | |
| | $p_A = p_B = p_D =$ | 30.30 | | |

forecloses Firm D, there is no unilateral deviation that increases an integrated firm's profit, because the business stealing effect outweighs the wholesale revenue effect. On the other hand, in the case of the competitive outcome, an integrated firm is unable to establish the foreclosure outcome unilaterally.

If wholesale competition is combined with margin squeeze regulation, the foreclosure equilibrium disappears—as under Timing Model (1)—and the competitive outcome constitutes the unique equilibrium. These results are summarized in Table A.6.

**Timing Model (4):** Like in Timing Model (2), the retailer as a follower maximizes its profit given the previously set wholesale price(s) and retail prices of the integrated firms, i.e., according to its best response function it chooses $p_D = BR(p_A, p_B) = \theta(\frac{1}{42} + \frac{5}{21}p_A + \frac{5}{21}p_B + \frac{1}{2}a)$. In stage I, integrated firms maximize profits simultaneously taking into account the reaction by Firm D in stage II. Optimal prices are given by $a_A^{Triopoly} = p_A^{Triopoly} = 51.25$, $p_B^{Triopoly} = 46.09$, and consequently $p_D^{Triopoly} = 64.67$. Accordingly, firms obtain profits $\pi_A^{Triopoly} = 15.07$, $\pi_B^{Triopoly} = 11.86$, and $\pi_D^{Triopoly} = 1.14$. Again, considering the retailer as a follower allows the integrated firms to internalize Firm D's reaction to their own prices which makes foreclosure relatively less profitable.

TABLE A.7: *Theoretical predictions for Timing Model (4).*

| | No regulation | | Margin squeeze regulation | |
|---|---|---|---|---|
| Wholesale monopoly | $a_A =$ | 51.25 | $a_A =$ | 51.25 |
| | $p_A =$ | 51.25 | $p_A =$ | 51.25 |
| | $p_B =$ | 46.09 | $p_B =$ | 46.09 |
| | $p_D =$ | 64.68 | $p_D =$ | 64.68 |
| Wholesale competition | $a_A = a_B =$ | 0.00 | $a_A = a_B =$ | 0.00 |
| | $p_A = p_B = p_D =$ | 30.30 | $p_A = p_B = p_D =$ | 30.30 |

The margin squeeze condition is non-binding, because Firm A's equilibrium prices in the case of an unregulated wholesale monopoly do not constitute a margin squeeze. Therefore, the theoretical prediction is the same as under an unregulated wholesale monopoly.

Having ruled out foreclosure as an equilibrium in the case of a wholesale monopoly, the same rationale holds under unregulated wholesale competition, because an integrated firm has always an incentive to deviate in the upstream market and charge the monopolistic wholesale price. Thus, as argued above, the competitive outcome remains as the unique equilibrium.

In consequence, under wholesale competition the margin squeeze regulation does not affect the theoretical prediction and the outcome is identical to the unregulated wholesale competition scenario, i.e., $a_A^{Competitive} = a_B^{Competitive} = 0$, $p_k^{Competitive} = 30.30$, and $\pi_k^{Competitive} = 5.79$, $\forall k \in \{A, B, D\}$. See Table A.7 for a summary of results.

## A.4 Coopetition in online advertising markets

### Prices and profits of special-interest CP given social login adoption decisions

*Scenario (b,b) – None of the CPs adopts the social login:* In this case market shares are given by $D_A^b = D_B^b = 1/2$ and equilibrium profits, which equal equilibrium prices, are obtained by simultaneously solving (7.3) and (7.4). Note that $n^e_{G(s)}(D^b_s,\delta,\alpha_{G(s)}) \equiv n_{G(s)}(D^b_s,\delta,0,\alpha_{G(s)})$ and $n^e_s(D^b_s,\delta,\alpha_s) = n_s(D^b_s,\delta,\alpha_s,0)$, i.e. view-throughs under exclusive advertising can be calculated by assuming a rival CP with targeting rate $\alpha = 0$. Thus, for the base scenario (b,b), conditions (7.3) and (7.4) can be stated as

$$n_{G(s)}(D^b_s,\delta,\alpha_s,\alpha_{G(s)}) - \Pi^{b,b}_G + n_s(D^b_s,\delta,\alpha_s,\alpha_{G(s)}) - \Pi^{b,b}_s = n^e_{G(s)}(D^b_s,\delta,\alpha_{G(s)}) - \Pi^{b,b}_G$$
$$n_{G(s)}(D^b_s,\delta,\alpha_s,\alpha_{G(s)}) - \Pi^{b,b}_G + n_s(D^b_s,\delta,\alpha_s,\alpha_{G(s)}) - \Pi^{b,b}_s = n^e_s(D^b_s,\delta,\alpha_s) - \Pi^{b,b}_s.$$

Solving simultaneously yields special-interest CP $s$'s equilibrium price and profit of

$$p^{b,b}_s = \Pi^{b,b}_s = \frac{1}{2}\delta\alpha^b_s \cdot (2(1-\alpha^b_G) + \delta(2\alpha^b_G - \alpha_s)).$$

*Scenario (l,b) – CP s adopts the social login, but its rival does not:* If CP $s$ adopts the social login, but its special-interest rival $-s$ does not, it gains a relative advantage with regard to the base utility that users derive from consuming its services, i.e. $u^l_s = u^b + \theta$ with $\theta \geq 0$. In consequence, it is able to increase its market share, as demand is now given by $D^l_s = \frac{\tau+\theta}{2\tau}$, whereas its rival experiences demand $D^l_{-s} = \frac{\tau-\theta}{2\tau}$. Moreover, CP $s$'s targeting rate is increased to $\alpha^l_s = \min\{\phi_s\alpha^b_s, 1\}$ with $\phi_s \geq 1$. On the other hand, adoption of the social login also increases the targeting rate of CP $G$ for the mass of consumers that consume services of CP $s$, i.e. $\alpha^l_{G(s)} = \min\{\phi_G\alpha^b_{G(s)}, 1\}$ with $\phi_G \geq 1$. Note that the targeting rate of CP $G$ with respect to users that consume services of the rival CP $-s$ is unaffected, i.e. $\alpha^l_{G(-s)} = \alpha^b_G$. Solving (7.3) and (7.4) analogous to scenario (b,b) yields price and profit of

$$p^{b,b}_s = \Pi^{l,b}_s = \frac{\delta\alpha^l_s(\tau+\theta)}{2\tau} \cdot \left(2 - \delta\alpha^l_s - 2\alpha^l_G(1-\delta)\right).$$

*Scenario (b,l) – CP s does not adopt the social loing, but its rival does:* This case is symmetric to case (l,b), but CP $s$ is now put at a disadvantage with regard to competition between the special-interest outlets as its rival benefits from consumers' increased valuation for its services due to the adoption of the social login. Whereas this diminishes its market share to $D_s^l = \frac{\tau-\theta}{2\tau}$, its own advertising rate together with the targeting rate of the general-interest CP for its mass of consumers $D_s$ is the same as in the base scenario, i.e. $\alpha_s^l = \alpha_s^b$ and $\alpha_{G(s)}^l = \alpha_{G(s)}^b$. Solving (7.3) and (7.4) analogous to scenario (b,b) yields price and profit of

$$p_s^{b,l} = \Pi_s^{b,l} = \frac{\delta\,\alpha_s^b\,(\tau-\theta)}{2\,\tau} \cdot \big(2\,(1-\alpha_G^b) - \delta\,(\alpha_s^b - 2\,\alpha_G^b)\big).$$

Note that $\Pi_s^{b,l}$ is symmetric to $\Pi_s^{l,b}$ with regard to the market share $\frac{\tau+\theta}{2\tau}$, given that targeting rates differ by the factor $\phi_k$.

*Scenario (l,l) – Both CPs adopt the social login:* If both CPs adopt the social login, users of both outlets benefit from an increased base utility when consuming the services of their respective CP, i.e., $u_s^l = u^b + \theta$. However, due to symmetry, CPs do not gain any competitive advantage and the surplus is appropriated exclusively by consumers. Thus, market shares are symmetric and identical to the base scenario (b,b), $D_s^l = D_s^b = \frac{1}{2}$. On the contrary, the impact of the social login on targeting rates is still effective, i.e. $\alpha_s^l = \phi_s \alpha_s^b$ for both $s = A, B$ and $\alpha_{G(A)}^l = \alpha_{G(B)}^l = \phi_G \alpha_{G(s)}^b$. Solving (7.3) and (7.4) analogous to scenario (b,b) yields price and profit of

$$p_s^{l,l} = \Pi_s^{l,l} = \frac{1}{2}\,\delta\,\alpha_s^l \cdot (2\,(1-\alpha_G^l) + \delta\,(2\,\alpha_G^l - \alpha_s^l)).$$

### Prices and profits of the general-interest CP given social login adoption decisions

*Scenario (b,b) – None of the CPs adopts the social login:* If none of the CPs adopts the social login, the targeting rates that determine the general-interest CP's advertising profit are given by the initial and symmetric targeting rates of special-interest CPs $A$

and $B$, i.e., $\alpha_A^b = \alpha_B^b = \alpha_s^b$, and by the general-interest CP's own initial targeting rate $\alpha_{G(A)}^b = \alpha_{G(B)}^b = \alpha_G^b$ for users of both CP $A$ and $B$. Solving (7.3) and (7.4) as shown for the profit-maximization of special-interest CPs yields CP $G$'s equilibrium price of

$$p_{G(s)}^{b,b} = \alpha_G^b\,(1-\delta)\cdot(1-\frac{1}{2}\alpha_G^b - \delta\,(\alpha_s^b - \frac{1}{2}\alpha_G^b),$$

resulting in an equilibrium profit of $\Pi_G^{b,b} = 2p_{G(s)}^{b,b}$.

*Scenarios (l,b) and (b,l) – One CP adopts the login, the rival does not:* If one special-interest CP adopts the social login, assume CP $A$, whereas the other special-interest CP does not, assume CP $B$, targeting rates are asymmetrically affected by the social login. The mass of users $D_A$, i.e., users that choose to visit CP $A$, can now be targeted at both outlets CP $A$ and CP $G$ with targeting rates $\alpha_A = \alpha_A^l = \phi_s\alpha_s^b$ and $\alpha_{G(A)} = \alpha_{G(A)}^l = \phi_G\alpha_{G(s)}^b$, respectively. In contrast, the targeting ability does not change with regard to $D_B$, i.e., users that choose to visit CP $B$. Thus CP $B$ and CP $G$ can target these users according to their initial targeting rates $\alpha_B = \alpha_s^b$ and $\alpha_{G(B)} = \alpha_{G(s)}^b$, respectively. Solving (7.3) and (7.4) as shown for the profit-maximization of special-interest CPs yields CP $G$'s equilibrium

$$\begin{aligned}
p_{G(A)}^{(l,b)} = p_{G(B)}^{(b,l)} &= \frac{-(\tau+\theta)(\delta-1)(\alpha_G^b\phi_G(\phi_G(\delta-1)\alpha_G^b - 2\delta\phi_s\alpha_s^b + 2)}{2\tau}\\
p_{G(B)}^{(l,b)} = p_{G(A)}^{(b,l)} &= \frac{\alpha_G^b(\tau-\theta)((\alpha_G^b - 2\alpha_s^b)\delta - \alpha_G^b + 2)(\delta-1)}{2\tau},
\end{aligned}$$

and a total profit of

$$\begin{aligned}
\Pi_G^{l,b} = \Pi_G^{b,l} = &\frac{1}{t}\alpha_G^b\,(\delta-1)\,(-\frac{1}{2}\,(\delta-1)\,(\phi_G^2\,\tau + \phi_G^2\,\theta + \tau - \theta)\,\alpha_G^b + ((\phi_s\,\phi_G + 1)\,\tau +\\
&\theta\,(\phi_s\,\phi_G - 1))\,\alpha_s^b\,\delta + t(-\phi_G - 1)\,\tau - \theta\,(\phi_G - 1)).
\end{aligned}$$

*Scenario (l,l) – Both CPs adopt the social login:* If both special-interest CPs adopt the social login, targeting rates are again symmetric with regard to CP $A$ and CP $B$, but are now increased by $\phi_s$ for special-interest CPs and $\phi_G$ for the general-interest CP, respectively. Consequently, targeting rates in this case are given by $\alpha_A = \alpha_B = \alpha_s^l = \phi_s \alpha_s^b$ and $\alpha_G = \alpha_{G(s)}^l = \phi_G \alpha_{G(s)}^b$. Solving (7.3) and (7.4) as shown for the profit-maximization of special-interest CPs yields CP $G$'s equilibrium price of

$$p_{G(s)}^{l,l} = (1-\delta)\alpha_G^l \cdot \left(1 - \delta\,\alpha_s^l - \frac{1}{2}(1-\delta)\alpha_G^l\right),$$

resulting in an equilibrium profit of $\Pi_G^{l,l} = 2p_{G(s)}^{l,l}$.

### Comparative Statics

**Critical threshold for adoption of the social login (CP $s$):** Given CP $s$'s rationale to adopt the login $\Delta_{l,b-b,b} = \Pi_s^{l,b} - \Pi_s^{b,b} > 0$, comparative statics with respect to the exogenous model parameters demonstrate the following effects.

*CP G's targeting rate $\alpha_{G(s)}^b$:*

$$\frac{\partial \Delta_{l,b-b,b}}{\partial \alpha_{G(s)}^b} = \frac{1}{2\tau} \cdot \left(((\phi_G\,\phi_s - 1)\tau + \theta\,\phi_G\,\phi_s)(\delta - 1)\delta\,\alpha_s^b\right) < 0.$$

*CP G's increase in targeting rate $\phi_G$:*

$$\frac{\partial \Delta_{l,b-b,b}}{\partial \phi_G} = \frac{1}{\tau} \cdot \left(\alpha_{G(s)}^b\,\alpha_s^b\,(\tau+\theta)\delta\,(\delta-1)\phi_s\right) < 0.$$

*CP s's targeting rate $\alpha_s^b$:*

$$\frac{\partial \Delta_{l,b-b,b}}{\partial \alpha_s^b} = \frac{1}{\tau} \cdot \big(\delta\,((-\alpha_s^b\,{\phi_s}^2\delta + (\delta\,\phi_G\,\alpha_{G(s)}^b - \phi_G\,\alpha_{G(s)}^b + 1)\phi_s + (-\alpha_{G(s)}^b + \alpha_s^b)\delta + \alpha_{G(s)}^b - 1)\tau + \theta\,\phi_s\,(\delta\,\phi_G\,\alpha_{G(s)}^b - \phi_s\,\alpha_s^b\,\delta - \phi_G\,\alpha_{G(s)}^b + 1))\big) < 0.$$

To show that the above condition is satisfied, solve $\frac{\partial \overline{\phi_s}}{\partial \alpha_s^b} = 0$ and reorder with respect to $\alpha_{G(s)}^b$. As it is assumed that $\alpha_{G(s)}^b > 0$, $\alpha_{G(s),0}^b := \frac{-\sqrt{\tau\,(\phi_G-1)^2(\tau+\theta)} - (\tau+\theta)\phi_G + \tau}{(\delta-1)((\tau+\theta)\phi_G^2 - \tau)}$ is the unique zeroing. It is easy to show that the effect of $\delta$ on $\alpha_{G(s),0}^b$ is positive. Therefore, $\delta = 0$ is used to calculate a lower bound for $\alpha_{G(s),0}^b$. As $\alpha_{G(s)}^l < 1$, solving $\alpha_{G(s),0}^b - 1/\phi_G = 0$ with respect to $\tau$ yields the unique solution $\tau = 0$. Any $\tau > 0$ yields $\alpha_{G(s),0}^b - 1/\phi_G > 0$, which contradicts the assumption $\alpha_{G(s)}^l = \alpha_{G(s)}^b \cdot \phi_G < 1$.

*CP s's increase in targeting rate $\phi_s$:*

$$\frac{\partial \Delta_{l,b-b,b}}{\partial \phi_s} = \frac{1}{\tau} \cdot \big(\delta\,\alpha_s^b\,(\tau + \theta)(\phi_G\,\delta\,\alpha_{G(s)}^b - \delta\,\alpha_s^b\,\phi_s - \phi_G\,\alpha_{G(s)}^b + 1)\big) > 0.$$

*CP s's increase in base utility $\theta$:*

$$\frac{\partial \Delta_{l,b-b,b}}{\partial \theta} = \frac{1}{2\tau} \cdot \big(\delta\,\phi_s\,\alpha_s^b\,(2\phi_G\,\delta\,\alpha_{G(s)}^b - \delta\,\alpha_s^b\,\phi_s - 2\phi_G\,\alpha_{G(s)}^b + 2)\big) > 0.$$

*Screen attention $\delta$:*

$$\frac{\partial \Delta_{l,b-b,b}}{\partial \delta} = \frac{2}{\tau} \cdot \big(((-1/2\,\alpha_s^b\,{\phi_s}^2\delta + (1/2 + \phi_G\,(\delta - 1/2)\alpha_{G(s)}^b)\phi_s + (-\delta + 1/2)\alpha_{G(s)}^b + 1/2\,\alpha_s^b\,\delta - 1/2)\tau + \theta\,(-1/2\phi_s\,\alpha_s^b\,\delta + 1/2 + \phi_G\,(\delta - 1/2)\alpha_{G(s)}^b)\phi_s)\alpha_s^b\big) > 0.$$

To show that the above condition is satisfied, solve $\frac{\partial \overline{\phi_s}}{\partial \delta} = 0$ and reorder with respect to $\tau$. The sign of the derivative changes twice: first at $\tau = 0$, second at $\tau < 0$ as long as $\alpha_s^b < 2\,\frac{\phi_G\,\alpha_{G(s)}^b - 1}{\phi_G\,\alpha_{G(s)}^b + \alpha_{G(s)}^b - 2}$, which is always satisfied under the assumption $\phi_G > 1$.

**Critical threshold for social login offer (CP $G$):** Given CP $G$'s rationale to offer the login $\Upsilon_{l,l-b,b} = \Pi_G^{l,l} - \Pi_G^{b,b}$, comparative statics yield that parameters $\theta$ and $\tau$ do not affect CP $G$'s profit. The effects of the remaining parameters are as follows.

*CP G's targeting rate $\alpha^b_{G(s)}$:*

$$\frac{\partial \Upsilon_{l,l-b,b}}{\partial \alpha^b_{G(s)}} = -2\left((\alpha^b_{G(s)}\,\phi_G{}^2 - \phi_s\,\phi_G\,\alpha^b_s + \alpha^b_s - \alpha^b_{G(s)})\delta - \alpha^b_{G(s)}\,\phi_G{}^2 + \phi_G + \alpha^b_{G(s)} - 1\right)(\delta - 1)$$
$$< 0.$$

To show that the above condition is satisfied, determine $\frac{\partial \widetilde{\phi_s}}{\partial \alpha^b_{G(s)}}$. The effect is unambiguously negative under the assumption $\phi_G > 1 \Leftrightarrow \phi_G^2 - 1 > 0$.

*CP G's increase in targeting rate $\phi_G$:*

$$\frac{\partial \Upsilon_{l,l-b,b}}{\partial \phi_G} = -2\left((\delta - 1)\phi_G\,\alpha^b_{G(s)} - \phi_s\,\alpha^b_s\,\delta + 1\right)(\delta - 1)\alpha^b_{G(s)} > 0.$$

*CP s's targeting rate $\alpha^b_s$:*

$$\frac{\partial \Upsilon_{l,l-b,b}}{\partial \alpha^b_s} = 2\,\alpha^b_{G(s)}\,(\delta - 1)\,(\phi_s\,\phi_G - 1)\delta < 0.$$

To show that the above condition is satisfied, solve $\frac{\partial \widetilde{\phi_s}}{\partial \alpha^b_s} = 0$ and reorder with respect to $\alpha^b_{G(s)}$. Given the assumptions $\alpha^l_{G(s)} < 1$ and $\phi_G > 1$, it is easy to show that the unique zeroing is outside of the relevant parameter range.

*CP s's increase in targeting rate $\phi_s$:*

$$\frac{\partial \Upsilon_{l,l-b,b}}{\partial \phi_s} = 2\,\alpha^b_{G(s)}\,(\delta - 1)\,\alpha^b_s\,\delta\,\phi_G < 0.$$

*Screen attention $\delta$:*

$$\frac{\partial \Upsilon_{l,l-b,b}}{\partial \delta} = -2\left(\left({\phi_G}^2\left(\delta-1\right)-\delta+1\right)\alpha^b_{G(s)} \right.$$
$$\left. + \left(1+\left(-2\phi_s\,\delta+\phi_s\right)\alpha^b_s\right)\phi_G - 1 + \left(2\delta-1\right)\alpha^b_s\right)\alpha^b_{G(s)} < 0.$$

The above condition is satisfied under the assumption $\phi_G > 1$.

**Critical threshold for profitability of the social login (CP $s$):** Given CP $s$'s condition for profitability $\Delta_{l,l-b,b} = \Pi_s^{l,l} - \Pi_s^{b,b}$, comparative statics yields similar effects to the comparative statics on CP $s$'s rationale to adopt the login (with the exceptions of $\theta$ and $\tau$) as the threshold for profitability is a special case of the latter. Parameters $\theta$ and $\tau$ do not have an impact on profitability. The effects of the remaining parameters are as follows.

*CP G's targeting rate $\alpha^b_{G(s)}$:*

$$\frac{\partial \Delta_{l,l-b,b}}{\partial \alpha^b_{G(s)}} = \alpha^b_s\,\delta\left(\phi_G\,\phi_s-1\right)\left(\delta-1\right) < 0.$$

*CP G's increase in targeting rate $\phi_G$:*

$$\frac{\partial \Delta_{l,l-b,b}}{\partial \phi_G} = \alpha^b_{G(s)}\left(\delta-1\right)\alpha^b_s\,\phi_s\,\delta < 0.$$

*CP s's targeting rate $\alpha^b_s$:*

$$\frac{\partial \Delta_{l,l-b,b}}{\partial \alpha^b_s} = \delta\left(-\alpha^b_s\,{\phi_s}^2+\phi_G\,\alpha^b_{G(s)}\,\phi_s+\alpha^b_s-\alpha^b_{G(s)}\delta-\phi_G\,\alpha^b_{G(s)}\,\phi_s+\phi_s+\alpha^b_{G(s)}-1\right) < 0.$$

*CP s's increase in targeting rate $\phi_s$:*

$$\frac{\partial \Delta_{l,l-b,b}}{\partial \phi_s} = \delta\,\alpha_s^b\,(\phi_G\,\delta\,\alpha_{G(s)}^b - \phi_s\,\alpha_s^b\,\delta - \phi_G\,\alpha_{G(s)}^b + 1) > 0.$$

*Screen attention $\delta$:*

$$\frac{\partial \Delta_{l,l-b,b}}{\partial \delta} = 2\,((\phi_G\,\phi_s - 1)(\delta - \frac{1}{2})\alpha_{G(s)}^b - \frac{1}{2}\,(\phi_s - 1)(\alpha_s^b\,\delta\,\phi_s + \alpha_s^b\,\delta - 1))\alpha_s^b > 0.$$

# Appendix B

# Statistical Analyses

## B.1 Oligopoly competition in continuous time

TABLE B.1: *Average degrees of tacit collusion over the entire time horizon across treatments.*

| Treatment | Obs. | $\bar{\varphi}^{Nash}_{p/q}$ | $\bar{\varphi}^{Nash}_{\Pi}$ | $\bar{\varphi}^{Walras}_{p/q}$ | $\bar{\varphi}^{Walras}_{\Pi}$ |
|---|---|---|---|---|---|
| DB2 | 12 | 0.832 | 0.806 | 0.916 | 0.951 |
| | | (0.249) | (0.302) | (0.124) | (0.075) |
| DB3 | 12 | 0.605 | 0.611 | 0.737 | 0.827 |
| | | (0.324) | (0.301) | (0.216) | (0.134) |
| DC2 | 12 | 0.627 | 0.437 | 0.907 | 0.965 |
| | | (0.550) | (1.030) | (0.138) | (0.064) |
| DC3 | 12 | 0.397 | 0.249 | 0.759 | 0.880 |
| | | (0.484) | (0.702) | (0.193) | (0.112) |
| RB2 | 12 | 0.769 | 0.712 | 0.884 | 0.928 |
| | | (0.343) | (0.453) | (0.172) | (0.113) |
| RB3 | 11 | 0.539 | 0.491 | 0.693 | 0.774 |
| | | (0.306) | (0.324) | (0.204) | (0.144) |
| RC2 | 12 | 0.789 | 0.688 | 0.947 | 0.980 |
| | | (0.259) | (0.344) | (0.065) | (0.021) |
| RC3 | 13 | 0.386 | 0.186 | 0.754 | 0.870 |
| | | (0.473) | (0.745) | (0.189) | (0.119) |

Standard deviations in parentheses.

## B.2 Wholesale competition and Open Access regulation

### Integrated firms' profit under unregulated wholesale monopoly

In order to investigate the effect of the access provider role in the case of a wholesale monopoly the following quantile regression is ran based on observations at the firm level:

$$\pi_{ijt} = \beta_0 + \beta_{Period} \cdot t + \beta_{Firm\,A} \cdot Firm\,A + \epsilon_{ijt},$$

where $\pi_{ijt}$ denotes the profit of integrated firm $i$ in market cohort $j$ and period $t$. The dummy variable $Firm\,A$ denotes whether the integrated firm represents the monopolistic wholesale provider.

TABLE B.2: *Quantile regression of integrated firms' profit $\pi_i$ in the case of a wholesale monopoly.*
*Baseline: Firm B in Wholesale Monopoly under No Regulation (WM-NR).*

| | $\pi_i$ |
|---|---|
| Firm A | 5.416*** |
| | (1.805) |
| Period | 0.001 |
| | (0.001) |
| Constant | 18.604*** |
| | (3.972) |
| Observations | 57,600 |

Clustered standard errors (by market cohort) in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

## Margin squeeze regulation in the case of a wholesale monopoly

TABLE B.3: *Quantile regression of wholesale market prices $a_m$, retail market prices $\psi_m$, integrated firms' average profits $\pi_{AB}$, retailer's profits $\pi_D$ and consumer surplus $\widetilde{CS}$ in the case of a wholesale monopoly.*
*Baseline: Wholesale Monopoly & No Regulation (WM-NR).*

| Covariate | (1) $a_m$ | (2) $\psi_m$ | (3) $\pi_{AB}$ | (4) $\pi_D$ | (5) $\widetilde{CS}$ |
|---|---|---|---|---|---|
| Margin squeeze regulation | 8.286 | 9.928 | 2.661 | 0.165 | $-0.083$ |
| | (15.569) | (8.354) | (1.786) | (0.784) | (0.083) |
| Period | 0.006 | $0.006^{***}$ | $0.001^{***}$ | $> -0.001$ | $> -0.001^{*}$ |
| | (0.007) | (0.002) | (0.001) | $(< 0.001)$ | $(< 0.001)$ |
| Constant | $60.290^{***}$ | $59.911^{***}$ | $15.112^{***}$ | $1.287^{*}$ | $0.338^{***}$ |
| | (11.192) | (7.423) | (1.991) | (0.703) | (0.096) |
| Observations | 55,200 | 55,200 | 55,200 | 55,200 | 55,200 |

Clustered standard errors (by market cohort) in parentheses.
$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

## Pairwise treatment effects

TABLE B.4: *Pairwise treatment effects on the wholesale market price $a_m$.*

| | No Regulation | | Margin Squeeze Regulation |
|---|---|---|---|
| Wholesale Monopoly | 73.573 | $\sim$ | 72.572 |
| | $\wedge^{*}$ | | $\sim$ |
| Wholesale Competition | 86.085 | $>^{*}$ | 83.082 |
| | $\vee^{***}$ | | $\vee^{**}$ |
| WC /w Price Commitment | 40.540 | $\sim$ | 49.049 |
| | $\wedge^{***}$ | | $\wedge^{**}$ |
| Wholesale Monopoly | 73.573 | | 72.572 |

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

TABLE B.5: *Pairwise treatment effects on the retail market price $\psi_m$.*

| | No Regulation | | Margin Squeeze Regulation |
|---|---|---|---|
| Wholesale Monopoly | 65.499 | $\sim$ | 83.124 |
| | $\wedge^{**}$ | | $\wedge^{**}$ |
| Wholesale Competition | 88.407 | $\sim$ | 92.281 |
| | $\vee^{***}$ | | $\vee^{***}$ |
| WC /w Price Commitment | 49.560 | $<^{*}$ | 67.415 |
| | $\wedge^{**}$ | | $\sim$ |
| Wholesale Monopoly | 65.499 | | 83.124 |

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

TABLE B.6: *Pairwise treatment effects on the average profit of integrated firms $\pi_{AB}$.*

| | No Regulation | | Margin Squeeze Regulation |
|---|---|---|---|
| Wholesale Monopoly | 16.383 | $\sim$ | 20.750 |
| | $\wedge^{**}$ | | $\sim$ |
| Wholesale Competition | 22.434 | $\sim$ | 22.802 |
| | $\vee^{***}$ | | $\vee^{***}$ |
| WC /w Price Commitment | 12.243 | $<^{*}$ | 15.866 |
| | $\wedge^{***}$ | | $\sim$ |
| Wholesale Monopoly | 16.383 | | 20.750 |

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

TABLE B.7: *Pairwise treatment effects on the retailer's profit $\pi_D$.*

| | No Regulation | | Margin Squeeze Regulation |
|---|---|---|---|
| Wholesale Monopoly | 0.899 | $\sim$ | 1.028 |
| | $\sim$ | | $\wedge^{**}$ |
| Wholesale Competition | 0.258 | $<^{***}$ | 2.339 |
| | $\wedge^{***}$ | | $\sim$ |
| WC /w Price Commitment | 2.491 | $\sim$ | 2.322 |
| | $\sim$ | | $\vee^{***}$ |
| Wholesale Monopoly | 0.899 | | 1.028 |

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

TABLE B.8: *Pairwise treatment effects on consumer surplus $\widetilde{CS}$.*

| | No Regulation | | Margin Squeeze Regulation |
|---|---|---|---|
| Wholesale Monopoly | 0.292 | $\sim$ | 0.153 |
| | $\vee^{*}$ | | $\vee^{**}$ |
| Wholesale Competition | 0.097 | $\sim$ | 0.062 |
| | $\wedge^{***}$ | | $\wedge^{***}$ |
| WC /w Price Commitment | 0.461 | $>^{**}$ | 0.298 |
| | $\vee^{***}$ | | $\vee^{*}$ |
| Wholesale Monopoly | 0.292 | | 0.153 |

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

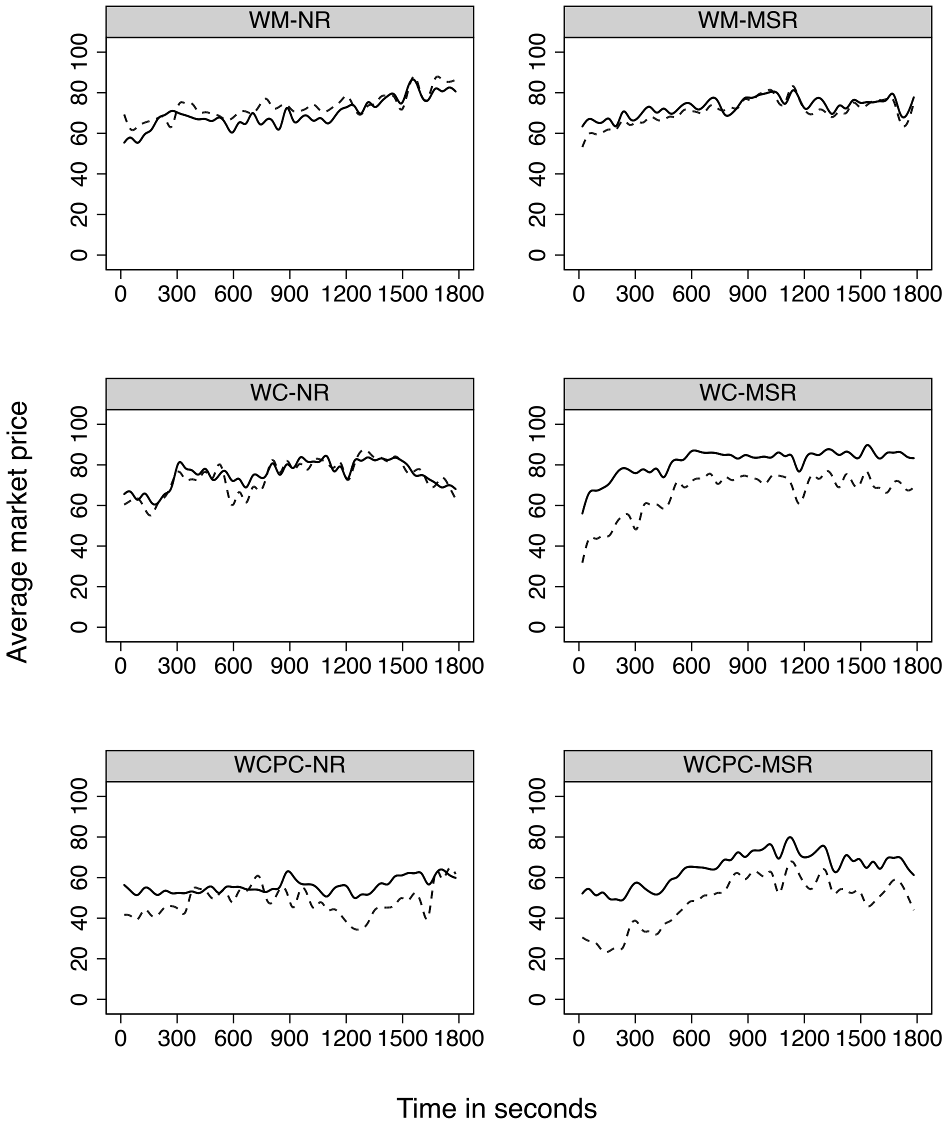
## Analysis based on mean values

TABLE B.9: *Average market prices, profits and consumer surplus per treatment.*

| Treatment | *Markets* | $N$ | $a_m$ | $\psi_m$ | $\pi_{AB}$ | $\pi_D$ | $\widetilde{CS}$ |
|---|---|---|---|---|---|---|---|
| WM-NR | 12 | 28,800 | 72.193 | 68.841 | 17.476 | 1.437 | 0.277 |
| WC-MSR | 11 | 26,400 | 72.368 | 74.253 | 18.808 | 1.366 | 0.230 |
| WC-NR | 9 | 21,600 | 76.960 | 78.092 | 19.611 | 1.441 | 0.197 |
| WC-MSR | 10 | 24,000 | 69.758 | 83.170 | 20.220 | 2.789 | 0.154 |
| WCPC-NR | 10 | 24,000 | 47.813 | 54.949 | 13.579 | 2.518 | 0.421 |
| WCPC-MSR | 12 | 28,800 | 52.429 | 67.187 | 16.277 | 3.165 | 0.306 |
| Total | 64 | 153,600 | 64.998 | 70.830 | 17.600 | 2.129 | 0.266 |

Averages are based on minutes [5,25] of the game phase.

FIGURE B.1: *Period averages of wholesale (dashed) and retail (solid) market prices. Graphs are plotted based on medians of 50 ticks.*



**Linear regression of market performance indicators**

$$
\begin{aligned}
X_{jt} = \beta_0 + \beta_{Period} \cdot t + \beta_{WC} \cdot WC & \\
+ \beta_{WCPC} \cdot WCPC & \\
+ \beta_{MSR} \cdot MSR & \\
+ \beta_{WCxMSR} \cdot WC \cdot MSR & \\
+ \beta_{WCPCxMSR} \cdot WCPC \cdot MSR & \\
+ \epsilon_{j,t} &
\end{aligned}
$$

TABLE B.10: *Linear regression of wholesale market prices $a_m$, retail market prices $\psi_m$, integrated firms' average profits $\pi_{AB}$, retailer's profits $\pi_D$ and consumer surplus $\widetilde{CS}$.*
*Baseline: Wholesale Monopoly under No Regulation (WM-NR).*

| Covariate | (1) $a_m$ | (2) $\psi_m$ | (3) $\pi_{AB}$ | (4) $\pi_D$ | (5) $\widetilde{CS}$ |
|---|---|---|---|---|---|
| Wholesale Competition (WC) | 4.768 | 9.251 | 2.135 | 0.004 | $-0.080$ |
| | (9.504) | (7.990) | (2.075) | (0.587) | (0.074) |
| WC w/ Price Competition (WC) | -24.380*** | $-13.892$* | $-3.897$* | 1.082*** | 0.144* |
| | (9.130) | (7.645) | (1.973) | (0.406) | (0.073) |
| Margin Squeeze Regulation (MSR) | 0.175 | 5.412 | 1.333 | $-0.071$ | $-0.047$ |
| | (8.100) | (6.624) | (1.692) | (0.383) | (0.062) |
| WC x MSR | -7.377 | $-0.334$ | $-0.724$ | 1.419* | 0.004 |
| | (12.972) | (10.884) | (2.800) | (0.755) | (0.102) |
| WCPC x MSR | 4.441 | 6.826 | 1.365 | 0.718 | $-0.067$ |
| | (12.501) | (10.339) | (2.668) | (0.573) | (0.099) |
| Period | 0.004** | 0.003*** | 0.001*** | $> -0.001$ | $> -0.001$*** |
| | (0.001) | (0.001) | ($< 0.001$) | ($< 0.001$) | ($< 0.001$) |
| Constant | 65.707*** | 62.550*** | 15.929*** | 1.539*** | 0.336*** |
| | (5.886) | (4.647) | (1.175) | (0.344) | (0.043) |
| Observations | 153,600 | 153,600 | 153,600 | 153,600 | 153,600 |

Clustered standard errors (by market cohort) in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

## B.3 Number effects and tacit collusion in oligopolies

### Meta-regressions of tacit collusion in oligopoly experiments that vary the number of competing firms

The use of multilevel regression models in meta-analyses has a shortcoming: The implicit weights associated to each observation, i.e., each treatment in a study, are of equal magnitude. However, each of these values stems from an experiment designed to predict a true effect. In other words, the averages of the degree of tacit collusion in each treatment of a study (i.e., the sample means) used in the analysis here are estimators of the true degree of tacit collusion (i.e., the population mean) in duopolies, triopolies, and quadropolies, respectively. Consequently, one might argue that the standard error of each sample mean should be considered as an indication of a sample mean's reliability. Meta-regression, a method vastly used in medical research (see, e.g., Higgins and Thompson, 2002), does exactly this by using the within-treatment standard errors as the standard deviations of the normal error terms in the model. More specifically, a random-effects meta-regression model is estimated which allows for between-study variance not explained by the covariates, i.e., the dummies for the number of firms.[1] This yields a weighted regression in which the inverse of the sum of the estimated between-study variance and the estimates' within-treatment variances are the individual weights associated to each treatment.

Table B.11 depicts the estimates of meta-regression models with the same dependent and independent variables as in the multilevel mixed-effects regressions. Note that the number of observations in the meta-regressions is lower than in the corresponding mixed-effects models, because standard errors of treatment averages could not be

[1] The estimates reported in Table B.11 are derived with the *metareg* command of the statistical software package *Stata* in its version 12. See Harbord and Higgins (2008) for further information on the command.

TABLE B.11: *Meta-regression of tacit collusion on number of competitors and competition model on the basis of most comparable treatments. Baseline: Triopoly & Bertrand competition.*

| Covariate | (1) $\varphi^{Nash}$ | (2) $\varphi^{Walras}$ |
|---|---|---|
| Duopoly | 0.269*** | 0.308*** |
| | (0.077) | (0.073) |
| Quadropoly | 0.026 | 0.083 |
| | (0.082) | (0.082) |
| Cournot | −0.182** | 0.320*** |
| | (0.076) | (0.067) |
| Constant | 0.023 | 0.064 |
| | (0.063) | (0.064) |
| Observations | 21 | 21 |

Baseline: Bertrand triopoly. Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

gathered from all studies.[2] For this reason, the treatment Easy in Bosch-Domènech and Vriend (2003) cannot be considered in the meta-regressions.

### Asymmetric market power and tacit collusion

Above and beyond number effects, asymmetry is expected to hinder coordination among firms as most of the economic literature suggests that symmetry is a driver of the ability to collude (see, e.g., Ivaldi et al., 2003; Fonseca and Normann, 2008). The hypothesis is thus that the degrees of tacit collusion based on Nash as well as Walrasian prices and profits are significantly lower in markets with asymmetric firms than in markets with symmetric firms, everything else being equal.

Although there is only a single difference in the parametrization between each asymmetry treatment and its symmetry counterpart, the necessary adjustment of $\Delta$ according to

[2]The standard errors of the degree of tacit collusion estimates are derived with the following relationship: $SE\left(\varphi_x^E\right) = \frac{1}{\sqrt{N}}\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(\frac{x-x^E}{x^{JPM}-x^E} - \frac{\bar{x}-x^E}{x^{JPM}-x^E}\right)^2} = \frac{1}{\sqrt{N}}\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(\frac{x-\bar{x}}{x^{JPM}-x^E}\right)^2} = \frac{1}{x^{JPM}-x^E}\frac{1}{\sqrt{N}}\sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x-\bar{x})^2} = \frac{1}{x^{JPM}-x^E}SE(x)$ with $N$ as the number of independent observations for the corresponding treatment.

TABLE B.12: *Multilevel mixed-effects linear regressions of tacit collusion on (a)symmetry of firms in triopolies.*
*Baseline: Symmetric Bertrand Triopoly (B3).*

| Covariate | (1) $\varphi^{Nash}$ | (2) $\varphi^{Walras}$ |
|---|---|---|
| Asymmetry | $-0.185$ | $-0.123$ |
| | (0.149) | (0.099) |
| Period | $-0.004^{***}$ | $-0.003^{***}$ |
| | (0.001) | (0.001) |
| Constant | $0.685^{***}$ | $0.790^{***}$ |
| | (0.106) | (0.070) |
| Cohorts | 24 | 24 |
| Observations | 1,440 | 1,440 |

Baseline: Symmetric Bertrand triopoly. Standard errors in parentheses.
$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

the number of firms in the market impedes a simultaneous analysis of asymmetry and the number of firms. In other words, the treatment dummy between asymmetric triopolies and quadropolies is not the same as the one between symmetric triopolies and quadropolies. Therefore, in order to assess the effect of the specific type of asymmetry implemented here, i.e., providing a single firm with a 50% higher Nash profit than its competitors, requires separate investigations of triopolies and quadropolies.

Tables B.12 and B.13 depict estimates of multilevel mixed-effects linear regression models of tacit collusion on symmetry and asymmetry of firms whilst controlling for heteroscedasticity via a random intercept for the cohort and a random slope for the time trend, i.e.,

$$
\begin{aligned}
\varphi^{E}_{k,t} = \beta_0 &+ \xi_k \\
&+ \beta_{Asymmetry} \cdot Asymmetry \\
&+ (\beta_{Period} + \beta_{Period,k}) \cdot t \\
&+ \epsilon_{k,t},
\end{aligned}
$$

TABLE B.13: *Multilevel mixed-effects linear regressions of tacit collusion on (a)symmetry of firms in quadropolies.*
*Baseline: Symmetric Bertrand Quadropoly (B4).*

| Covariate | (1) $\varphi^{Nash}$ | (2) $\varphi^{Walras}$ |
|---|---|---|
| Asymmetry | $-0.179^{**}$ | $-0.135^{**}$ |
| | (0.075) | (0.056) |
| Period | $-0.001$ | $-0.001$ |
| | (0.001) | (0.001) |
| Constant | $0.456^{***}$ | $0.592^{***}$ |
| | (0.054) | (0.040) |
| Cohorts | 33 | 33 |
| Observations | 1,980 | 1,980 |

Baseline: Symmetric Bertrand quadropoly. Standard errors in parentheses.
$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

in triopolies and quadropolies, respectively. For maximum comparability, only the Bertrand treatments are included in the analysis for which there is data with both symmetric and asymmetric firms. In line with the hypothesis, the degree of tacit collusion is 18 pp (13 pp) lower in quadropolies with asymmetric compared to symmetric firms relative to the Nash (Walrasian) equilibrium. The degree of tacit collusion is not significantly lower with asymmetry in triopolies, although the average effect size of asymmetry is similar to the effect found for quadropolies. Given the lower number of observations this points to a lack of statistical power in the analysis of triopolies.

Prominent theories of fairness and equity in the behavioral sciences (e.g., Fehr and Schmidt, 1999; Bolton and Ockenfels, 2000) suggest that cooperation is harder to sustain in asymmetric than in symmetric games, which is in line with the finding here. In an effort to assess whether social preferences in fact account for the effect of asymmetry on tacit collusion, subjects' social value orientation is measured using the Murphy et al. (2011) questionnaire, which is filled out by every participant directly after the oligopoly experiment at the end of a session, with the exception of one session with twelve participants in May 2016. Remember that incumbent firms are provided with higher market power than entrants in the asymmetry treatments. A comparison of the continuous social value orientation index reveals no differences between incumbents and entrants or subjects in triopolies and quadropolies. Among the four idealized social orientations of altruistic, prosocial, individualistic, and competitive behavior, the average participant is on the verge of prosocial and individualistic behavior. This finding is further corroborated in a categorical analysis which matches subjects to a single category. According to the classification, 43% of subjects are prosocials, 46% are individualists, and none are altruists or of competitive type—the remaining 11% cannot be assigned due to incomplete questionnaires. Again social orientations are not significantly different between subjects acting as firms of different types or participating in different treatments. Furthermore, social value orientations are neither correlated with the degree of tacit collusion connected to price decisions nor with subjects' total profit in the experiment. In sum, these findings suggest that social orientations cannot explain why asymmetric firms collude less than symmetric firms.

The experimental evidence for quadropolies suggests that asymmetry fosters competition between firms in a market considerably and significantly. Put into context, the effect size of implementing asymmetry in a quadropoly by increasing the market power of a single firm is comparable to the number effect on tacit collusion between markets with two and three firms as well as between markets with three and four firms.

## Supplementary tables and figures

TABLE B.14: *Multilevel mixed-effects linear regressions of tacit collusion on number of competitors and competition model on the basis of all treatments. Baseline: Triopoly & Bertrand competition.*

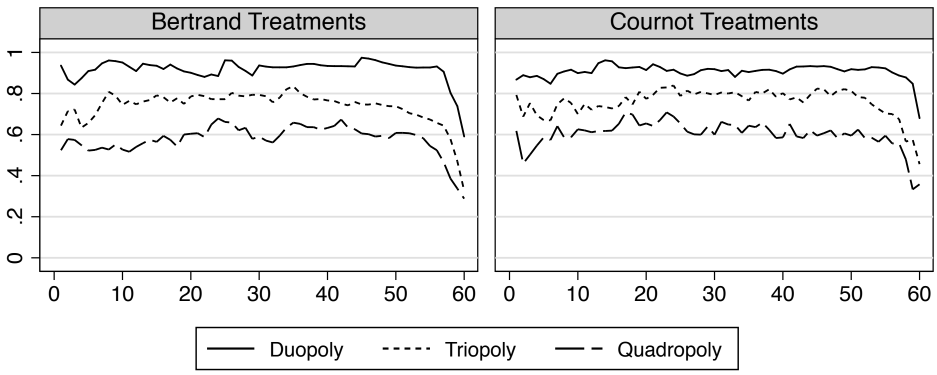
| Covariate | (1) $\varphi^{Nash}$ | (2) $\varphi^{Walras}$ |
|---|---|---|
| Duopoly | 0.208*** | 0.233*** |
| | (0.037) | (0.030) |
| Quadropoly | −0.041 | −0.009 |
| | (0.046) | (0.037) |
| Cournot | −0.249*** | 0.316*** |
| | (0.074) | (0.047) |
| Constant | 0.077 | 0.138*** |
| | (0.056) | (0.047) |
| Groups ($s$) | 9 | 9 |
| Groups ($m$) | 10 | 10 |
| Observations | 23 | 23 |

Baseline: Bertrand triopoly. Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

TABLE B.15: *Inter-study average degrees of tacit collusion and one-tailed matched-samples Wilcoxon signed-rank tests on the basis of all treatments.*

| | Studies | $\varphi^{Nash}$ | $\varphi^{Walras}$ |
|---|---|---|---|
| *2 vs. 3* | | | |
| Duopoly | 7 | 0.110 | 0.480 |
| Triopoly | 7 | −0.079 | 0.260 |
| $p$ value | 7 | 0.009 | 0.009 |
| *2 vs. 4* | | | |
| Duopoly | 6 | 0.302 | 0.452 |
| Quadropoly | 6 | 0.025 | 0.204 |
| $p$ value | 6 | 0.014 | 0.014 |
| *3 vs. 4* | | | |
| Triopoly | 3 | 0.035 | 0.196 |
| Quadropoly | 3 | 0.049 | 0.174 |
| $p$ value | 3 | 0.946 | 0.500 |

FIGURE B.2: *Average degrees of tacit collusion $\varphi^{Walras}$ over periods across treatments.*



# Appendix C

# Experimental Instructions

For each experiment, the instructions of only one exemplary treatment are reported in the following. The instructions for the other treatments are identical except for text passages that describe the specifics of the particular treatment. Note that the experimental instructions are translated from German and are only translations for information; they are not intended to be used in the lab. The instructions in the original language are carefully polished in grammar, style, comprehensibility, and avoidance of strategic guidance.

## C.1 Oligopoly competition in continuous time

*The following experimental instructions have been used for the RB3 treatment.*

### Preliminary remarks

Welcome to the experiment and thank you very much for your participation. In this 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. Throughout the experiment we will use the currency Euro and its subunit cent. The Euro that you will have earned by the end of the experiment will be paid to you in cash.

### Experimental structure

There are three firms competing with each other:

- Firm A
- Firm B
- Firm C

Each firm is represented by one participant of the experiment. Throughout the experiment the same firms compete with each other. Which firm you represent is randomly chosen at the beginning of the experiment. Each firm offers a good that is demanded by consumers. There are no cost for producing these goods. You choose the price at which you want to sell your good. The quantity demanded of your good is determined by your price. Thereby, the following holds:

- The higher your price, the lower the quantity demanded of your good. Thereby, the quantity demanded of your good can fall to zero.
- The higher a price of the other firms, the higher the quantity demanded of your good. Thereby, only prices of firms selling a positive quantity are relevant.

Your profit is calculated by multiplying your price with the quantity demanded of your good.

## Experimental procedure

The experiment is composed of two stages. At stage one you choose your initial price. Before making the final decision, you can test how a price combination affects the quantities and profits of all firms. After all firms made their final decision by pressing the button "Finalize decision", the second stage of the experiment begins. The second stage lasts exactly 30 minutes. During this time all decisions are made in real-time and without any interruptions. Your price decision is valid until you change your price. Every decision of a firm is immediately visible for all other firms.

## Software display

FIGURE C.1: *Display of the experimental software.*

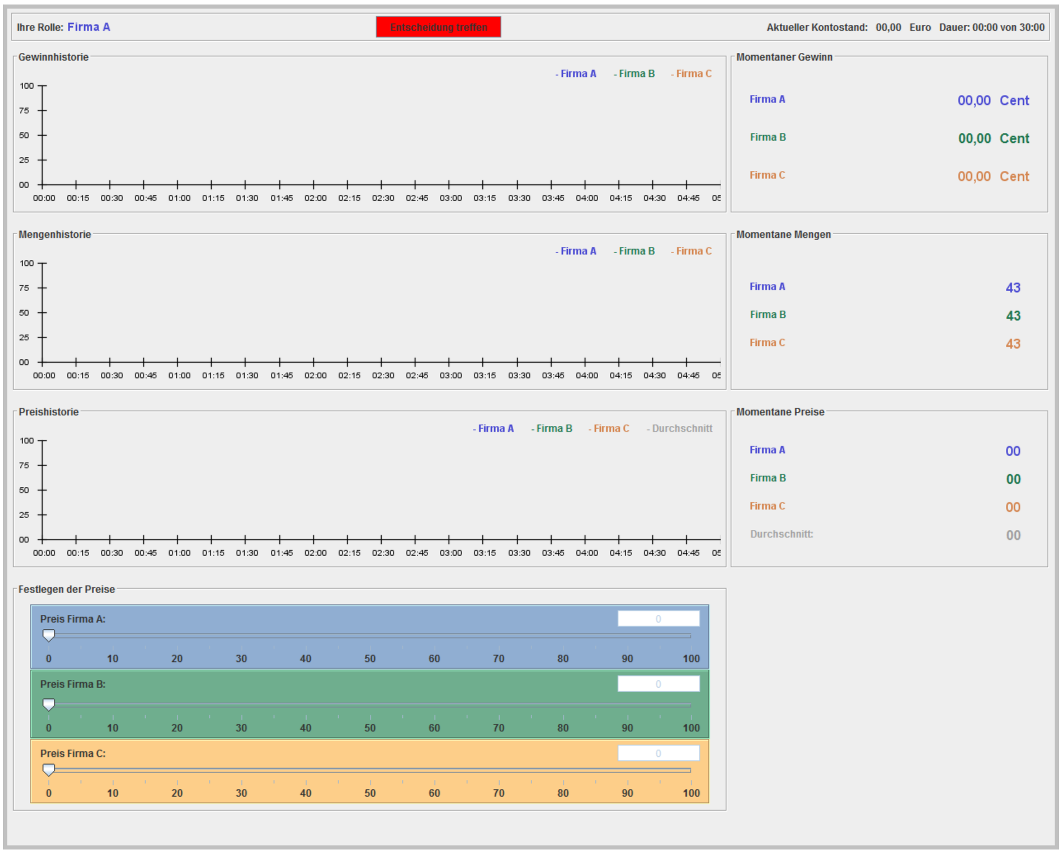



Figure C.1 depicts the display of the experimental software. To distinguish the firms, their information is colored as follows:

- Firm A: BLUE
- Firm B: GREEN

- Firm C: ORANGE

In the following, the individual parts of the display will be explained bottom up.

#### Decision and testing environment

On the left side you can set your price by using the slider of the firm. Please be aware that you can use all sliders during the first stage of the experiment and only the slider of your own firm during the second stage. During the second stage the sliders show the current prices of the other firms.

#### Prices

On the left side the history of all firms' prices as well as the average price is visualized. On the right side the current prices are displayed.

#### Quantities

On the left side the history of all firms' quantities is visualized. On the right side the current quantities are displayed.

#### Profits

On the left side the history of all firms' profits is visualized. On the right side the current profits are displayed. Please be aware that current profits are scaled to the profit you would earn if the current combination of all prices would be held for 30 seconds. As soon as one firm changes its price, the profits are recalculated. Your current profit is added to your account proportionally several times per second.

#### Status of the experiment

On the left side it is displayed which firm you represent. Figure C.1 shows this for firm A as an example. During the first stage there is a button "Finalize decision" in the middle of the display. Please press it when you are ready to finalize your decision. On the right side your current account balance and the remaining duration of the experiment is displayed. Your current account balance is the sum of all realized profits.

### Concluding remarks

Before the experiment starts, you will be asked some comprehension questions on the screen with regard to the understanding of the rules and the course of the experiment. Please enter the respective answers into your computer. Afterwards, the experiment will start automatically and it will be displayed which firm you represent.

In case of any questions, 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 your 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.

## C.2 Wholesale competition and Open Access regulation

*The following experimental instructions have been used for the $WCPC - MSR$ treatment.*

### Preliminary remarks

Welcome to the experiment and thank you very much for your participation.In this 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. Throughout the experiment we will use the currency Euro and its subunits cent. At the beginning of the experiment your account balance is EUR 5.00. At the end of the experiment, the final account balance will be paid to you in cash.

During the experiment you represent a firm which is selling a good to consumers. Next to you, there are two other firms which are competing with you. All your decisions are made in real time, thus, they are immediately effective and visible to all other firms. Over the entire time horizon of the experiment, you play together with the same firms.

### Experimental structure

There are three firms:

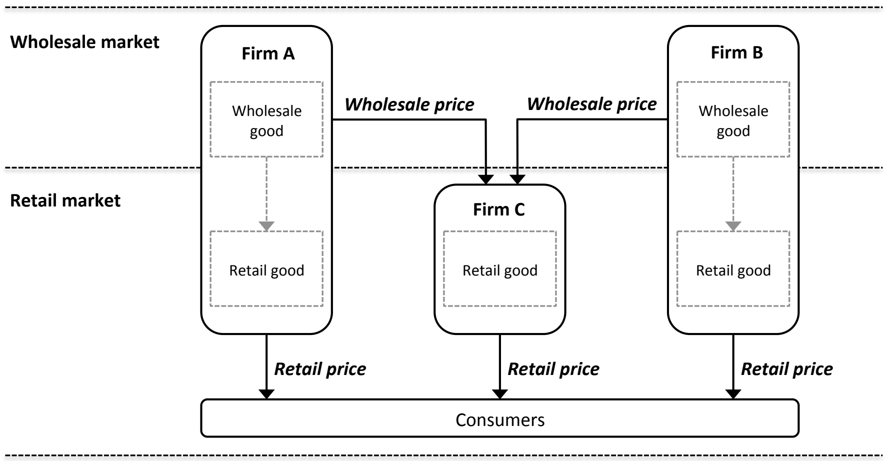
- Firm A
- Firm B
- Firm C

Firm A and Firm B are represented by participants of the experiment. Firm C acts computerized. Which firm you represent is randomly chosen at the beginning of the experiment and does not change over the entire experiment. Furthermore there are two markets:

- Wholesale market
- Retail market

Figure C.2 visualizes the structure of the experiment. Each of the three firms offers a retail product on the retail market and chooses its retail price. In order to produce the retail product each firm needs a wholesale product. Only Firm A and Firm B offer the wholesale product in the wholesale market and choose their respective wholesale prices. Firm C has to buy the wholesale product from one of the two other firms in order to be able to offer its retail product.

FIGURE C.2: *Structure of the experiment.*




#### Wholesale Market

The wholesale products of Firm A and Firm B are equal. Thereby, the following holds:

- Firm C chooses automatically the cheaper wholesale product to satisfy its demand.
- If Firm A and Firm B offer the identical wholesale price, Firm C chooses the wholesale product from the firm which had previously offered the lower price.
- If Firm A and Firm B offer the identical wholesale price at the beginning, Firm C chooses randomly from which firm it purchases the wholesale product.

There are no handling costs for the wholesale product. The prices of the wholesale products range from 0 to 100.

#### Retail market

The retail products differ between firms. The demand of your retail product depends on your retail price and the retail prices of the other firms. Thereby, the following holds under the assumption that the other retail prices remain unchanged:

- If you increase your retail price, the demand of your retail product decreases.
- If one of the other firms increases its retail price, the demand of your retail products increases.
- If all firms increase their retail price, the total demand of all retail products decreases.

If your retail price is located below the average of all three retail prices, the demand of your retail product increases. If your retail price is located above the average of all three retail prices, the demand of your retail product decreases. The extent of the deviation of your retail price from the average of all three retail prices determines the magnitude of this effect. If your retail price is above the average of all three retail prices, the demand of your retail product may fall to zero. Firm C chooses its profit-maximizing retail price in reaction to the effective wholesale price and the retail prices chosen by Firm A and Firm B.

There are no handling costs for the retail product. The prices of the retail products range from 0 to 100.

**Profits**

The profits of the three firms depend on the retail and wholesale prices. The calculations for the profits of Firm A and Firm B depend on Firm C's decision which firm to choose as its wholesale provider.

If Firm C chooses to purchase its wholesale product from Firm A, the following holds for the profits of each firm:

$$Profit_A = Retail\ Price_A \cdot Demand_A + Wholesale\ Price_A \cdot Demand_C$$
$$Profit_B = Retail\ Price_B \cdot Demand_B$$
$$Profit_C = (Retail\ Price_C - Wholesale\ price_A) \cdot Demand_C$$

If Firm C chooses to purchase its wholesale product from Firm B, the following holds for the profits of each firm:

$$Profit_A = Retail\ Price_A \cdot Demand_A$$
$$Profit_B = Retail\ Price_B \cdot Demand_B + Wholesale\ Price_B \cdot Demand_C$$
$$Profit_C = (Retail\ Price_C - Wholesale\ Price_B) \cdot Demand_C$$

## Experimental procedure

The experiment is composed of two stages. At the first stage, as Firm A or Firm B, you choose your initial retail price and your initial wholesale price. Before making your final decision, you can test how a price combination affects the profits of all three firms. This does not influence your account balance. After all firms have made their initial price decision and have confirmed their decisions with a click on "apply initial prices", the second stage of the experiment starts.

The second stage lasts exactly 30 minutes. During this period of time, all decisions are made in real time and without any interruptions. Your price decision remains effective until you change your price. Note that subsequent to a change of your wholesale price, the price cannot be changed again for the next 30 seconds. Furthermore, please be aware that your wholesale price can not be located above your retail price.

## Software display

FIGURE C.3: *Display of the experimental software.*

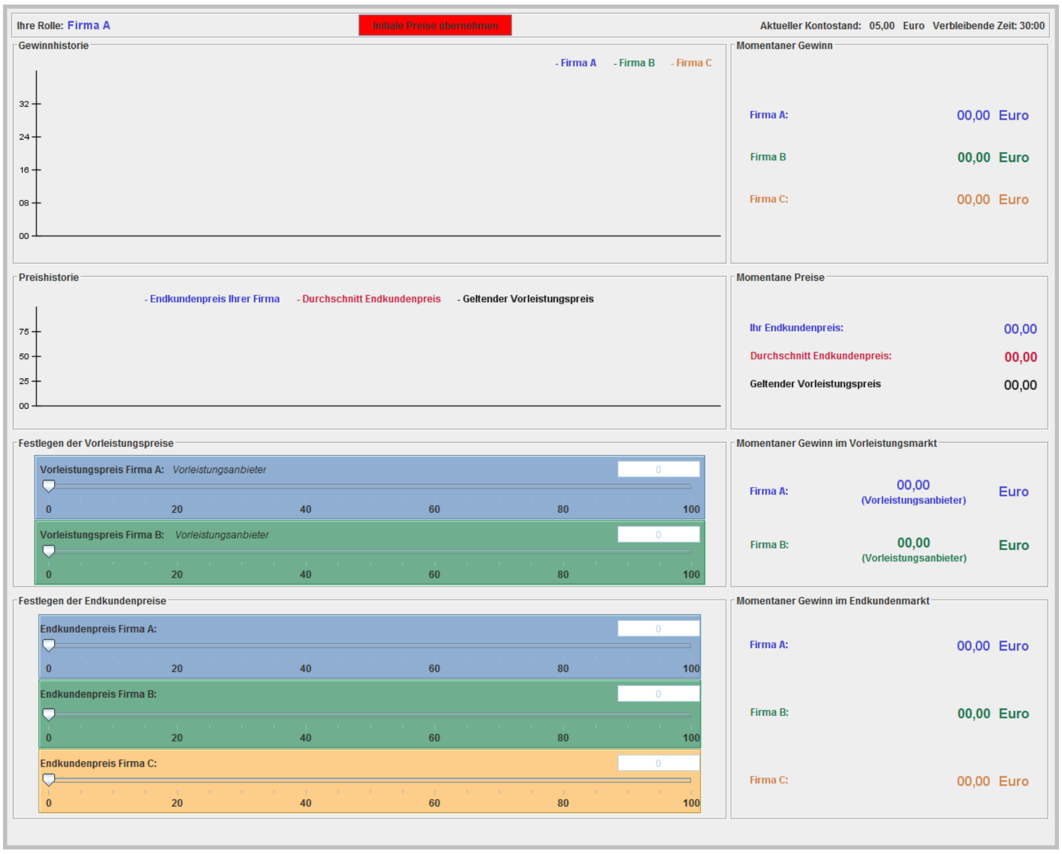



Figure C.3 depicts the display of the exeriment software. In order to distinguish the firms, their labels are colored as follows:

- Firm A: BLUE
- Firm B: GREEN
- Firm C: ORANGE

In the following, the individual sections of the display will be explained from the bottom up:

**Experimental progress**

On the left-hand side, it is denoted whether you represent Firm A or Firm B. The figure illustrates this exemplarily for Firm A. On the right-hand side, your current account balance as well as the remaining duration of the experiment is displayed. Your current account balance consists of the initial balance of EUR 5.00 and the additionally earned profits during the experiment.

**Current profits and profit history**

On the right-hand side, the current profits of all firms are displayed. Note that current profits are scaled to the profit you would earn, if the current combination of all prices would be held over the entire 30 minutes of the experiment. As soon as one of the prices changes, the current profits are recalculated. On the left-hand side, the history of the current profits is displayed.

**Current prices and price history**

On the right-hand side, the current prices of all three firms are displayed. The effective wholesale price is always the lower wholesale price of both wholesale prices. On the left-hand side, the history of your retail price, the average retail price of all three firms and the effective wholesale price is displayed.

**Wholesale prices and current profits in the wholesale market**

On the left-hand side, Firm A and Firm B choose their wholesale prices. Be aware that Firm C offers no wholesale product and thus cannot choose a wholesale price. The wholesale price can be set with the corresponding slider by using the mouse or the arrow keys on the keyboard. Note that you can move all sliders at the first stage of the experiment and only the slider of your firm at the second stage of the experiment. The sliders of the other firms show their current wholesale prices. On the right-hand side the current profits in the wholesale market are displayed. Furthermore it is displayed which firms sells its wholesale product to Firm C. Note that subsequent to a change of your wholesale price, the price cannot be changed again for the next 30 seconds. Furthermore, please be aware that your wholesale price can not be located above your retail price.

**Retail prices and current profits in the retail market**

On the left-hand side, all of the three firms choose their retail price. The retail price can be set with the corresponding slider by using the mouse or the arrow keys on the keyboard. Note that you can move all sliders at the first stage of the experiment and only the slider of your firm at the second stage of the experiment. The sliders of the other firms show their current retail prices. On the right-hand side, the current profits in the retail market are displayed. Note that the displayed current profit of Firm C already includes the costs for the wholesale product.

## Concluding remarks

Before the experiment starts, you will be asked a set of comprehension questions, displayed on the computer screen, that cover the rules and the procedure of the experiment. Please enter the respective answers. Thereupon, the experiment will start automatically and it is displayed which firm you represent.

In case of any questions during the experiment, please remain seated and inform the person in charge of the experiment by the means of a hand gesture. Please wait until the person in charge of the experiment has arrived at your seat. Talk as quietly as possible when asking your question. Please remain seated after the end of the experiment and wait for further instructions from the person in charge of the experiment.

## C.3 Number effects and tacit collusion in oligopolies

*The following experimental instructions have been used for the B4A treatment.*

### Preliminary remarks

Welcome to the experiment and thank you very much for your participation. In this 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. Throughout the experiment we will use the currency Euro and its subunit cent. The Euro that you will have earned by the end of the experiment will be paid to you in cash.

### Experimental structure

There are four firms competing with each other:

- Firm A
- Firm B
- Firm C
- Firm D

Each firm is represented by one participant of the experiment. Throughout the experiment the same firms compete with each other. Which firm you represent is randomly chosen at the beginning of the experiment. Each firm offers a good that is demanded by consumers. There are no cost for producing these goods. You choose the price at which you want to sell your good. The quantity demanded of your good is determined by your price. Thereby, the following holds:

- The higher your price, the lower the quantity demanded of your good. Thereby, the quantity demanded of your good can fall to zero.
- The higher a price of the other firms, the higher the quantity demanded of your good. Thereby, only prices of firms selling a positive quantity are relevant.

Please be aware that the quantity demanded of Firm A differs from the quantity demanded of any other firm, everything else being equal. If all firms choose the same price, the quantity demanded of Firm A is greater than the quantity demanded of any other single firm. Additionally, the following holds:

- If Firm A raises its price, the quantity demanded of Firm A decreases less than the quantity of any other firm if it raises its price.
- If another firm raises its price, the quantity demanded of Firm A increases more than the quantity of any other firm.

Your profit is calculated by multiplying your price with the quantity demanded of your good.

### Experimental procedure

The experiment lasts 60 periods. In each period you chose your price. Before making the final decision, you can test how a price combination affects the quantities and profits of all firms. After all firms made their final decision by pressing the button "Finalize decision", quantities and profits are calculated and the next period begins.

### Software display

FIGURE C.4: *Display of the experimental software.*

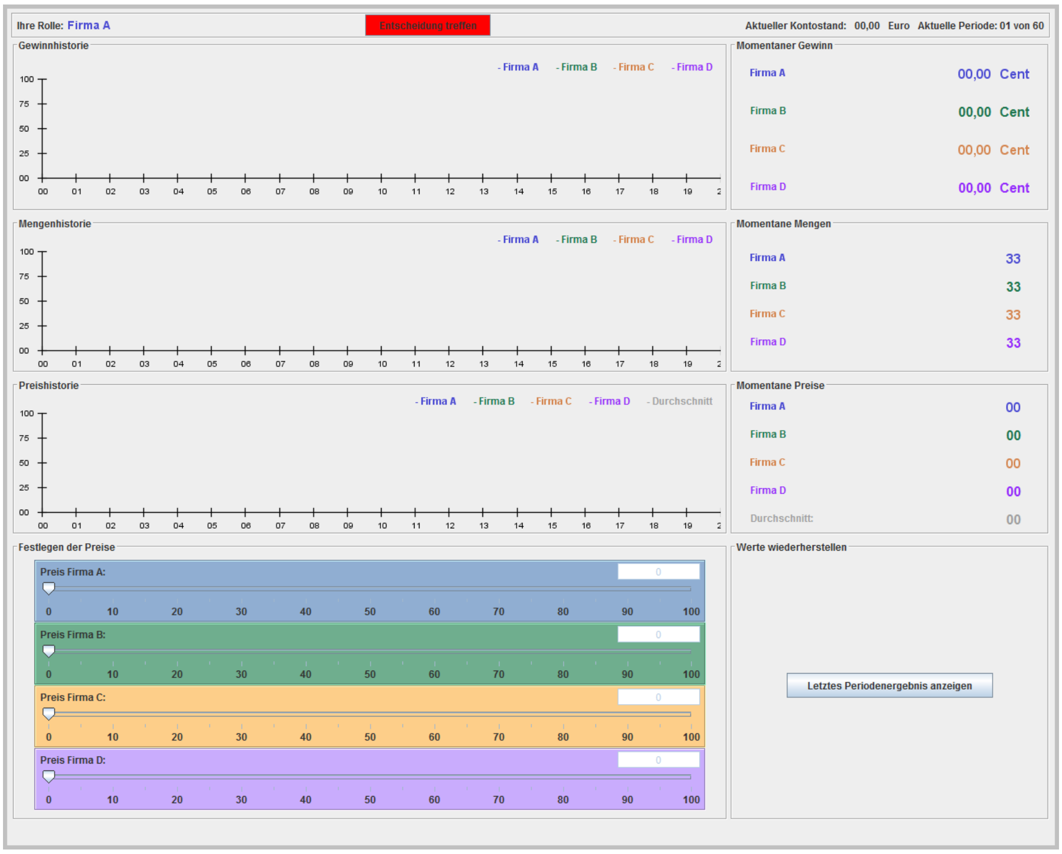


Figure C.4 depicts the display of the experimental software. To distinguish the firms, their information is colored as follows:

- Firm A: BLUE
- Firm B: GREEN
- Firm C: ORANGE
- Firm D: PURPLE

In the following, the individual parts of the display will be explained bottom up.

#### Decision and testing environment

On the left side you can set your price by using the slider of your firm. At the beginning of a period the sliders show the prices of the firms of the previous period. Before making the final decision, you can test the consequences of your price decision by adjusting the sliders of the other firms to your expectations. As soon as you release a slider, the quantities and profits that would result in the next period if the currently set prices in the testing environment get chosen are displayed on the right side of the screen above the sliders. On the right side you can reset the sliders to the prices of the last period by pressing the button "Show last period results".

#### Prices

On the left side the history of all firms' prices as well as the average price is visualized. On the right side the currently set prices in the testing environment are displayed.

#### Quantities

On the left side the history of all firms' quantities is visualized. On the right side the quantities that would result in the next period if the currently set prices in the testing environment get chosen are displayed.

#### Profits

On the left side the history of all firms' profits is visualized. On the right side the profits that would result in the next period if the currently set prices in the testing environment get chosen are displayed.

**Status of the experiment**

On the left side it is displayed which firm you represent. Figure C.4 shows this for firm A as an example. In the middle of the display is the button “Finalize decision”. Please press it when you are ready to finalize your decision. On the right side your current account balance and the current period of the experiment is displayed. Your current account balance is the sum of all realised profits.

## Concluding remarks

Before the experiment starts, you will be asked some comprehension questions on the screen with regard to the understanding of the rules and the course of the experiment. Please enter the respective answers into your computer. Afterwards, the experiment will start automatically and it will be displayed which firm you represent.

In case of any questions, 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 your 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.

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# List of Abbreviations

| | |
|---|---|
| API | application programming interface |
| CLEC | competitive local exchange carriers |
| CP | content provider |
| CPA | cost-per-action |
| CPC | cost-per-click |
| CPM | cost-per-mille |
| EU | European Union |
| FBC | facility-based competition |
| ICT | information and communications technology |
| IO | Industrial Organization |
| IP | Internet Protocol |
| IS | Information Systems |
| JPM | joint profit maximization |
| LRIC | long-run incremental costs |
| MSR | margin squeeze regulation |

| | |
|---|---|
| NGA | next-generation access |
| NGAN | next-generation access network |
| NR | no regulation |
| NRA | national regulatory authority |
| | |
| OA | Open Access |
| OSI | Open Systems Interconnection |
| | |
| pp | percentage points |
| PPP | public-private-partnership |
| | |
| QoS | quality of service |
| | |
| RRC | raising rivals' costs |
| | |
| SBC | service-based competition |
| SMPT | Single Monopoly Profit Theorem |
| SOE | state-owned enterprise |
| | |
| WC | Wholesale Competition |
| WCPC | Wholesale Competition with Price Commitment |
| WM | Wholesale Monopoly |

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