Essays on industrial organisation:
Digital platform competition, technology licensing, and vertical markets

Atle Haugen

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Samandrag

Avhandlinga inneheld fire kapittel som tar for seg næringsøkonomiske emne innanfor digitale plattformer og vertikale marknader. Det første kapittelet adresserer korleis konkurranse mellom digitale plattformer blir påverka av målrettingsteknologiar, strengare personvernregulering og kor mange abonnement kundane kjøper. Sidan målrettingskvaliteten aukar dess meir data ein puttar inn i teknologien, er det desto viktigare for plattformene å tiltrekke seg fleire brukarar. Der tidlegare litteratur har vist at målretting kan føre til ein veldig sterk konkurranse når brukarane berre abonnerer på éi plattform av gangen, viser vi at likevektsprofitten er høgare med målretting enn utan når vi tillèt brukarane å abonnere på fleire plattformer samstundes. Det andre kapittelet studerer konkurranseeffektane av krysslisensiering mellom digitale plattformer. Krysslisensiering legg til rette for teknologioverføring, som fremjar konkurranse og innovasjon. Likevel veit vi frå studiar på tradisjonelle marknader at denne type avtalar også potensielt har konkurranseskadelege effektar, og slik gir insentiv til auka prisar. I ein modell for tosidige marknader, finn eg at krysslisensiering er mindre konkurranseskadeleg når det er positive nettverkseffektar, og i ytste konsekvens at prisane kan falle med lisensavgifta, som følgje av at plattforma internaliserer nettverkseffektar. Det tredje kapittelet studerer insentiva til leverandørar og detaljistar i vertikale marknader når innsidealternativ fører til prisdiskriminering i favør av større detaljistar. Der eksisterande litteratur gir eintydige resultat: ein leverandør vil ønske å binde seg til uniform prising, og forbrukarane blir skadelidande; viser vi med ein modell med endogene innsidealternativ at resultatet er meir tvitydig når vi opnar for differensiering på detaljistleddet. Det fjerde og siste kapittelet presenterer eit undervisningsopplegg for å lære vekk sentrale omgrep i økonomifaget til økonomistudentar. Undervisingsopplegget skal stimulere til aktiv læring og diskusjonar om mellom anna teknologilisensiering og immaterielle rettar.

Abstract

This thesis consists of four chapters on the industrial organisation of digital platforms and vertical markets. The first chapter addresses how competition between digital platforms is affected by targeting technologies, stricter privacy regulation, and consumer multi-homing. Since the quality of targeting technologies improves with consumer data, targeting increases the importance of attracting consumers. Whereas previous literature has shown that this could result in fierce competition when consumers subscribe to only one platform (i.e., single-home), we find that targeting softens the competition over consumers when we allow consumers to have multiple subscriptions (i.e., multi-home). This might imply that equilibrium profits are higher with targeting than without. The second chapter studies the competitive effects of cross-licensing contracts between digital platforms. In one-sided markets, cross-licensing has potential anti-competitive effects. I find in a two-sided model that positive network effects might alleviate the anti-competitive effects of cross-licensing, and even flip the outcome. The third chapter studies the incentives of dominant suppliers to commit to uniform pricing in wholesale markets when inside options induce size-based wholesale price discrimination in favour of the large retailer. Seminal literature has provided clear-cut results. In a model with endogenous inside options, we show that the outcome is ambiguous when we allow retailers to be differentiated. The fourth and final chapter presents two classroom experiments on technology licensing, which has been applied to teach central concepts of economics to business students. The classroom experiments stimulate discussions of, among others, technology licensing and intellectual property rights.

Acknowledgements

> *If you want to win something, run one hundred meters. If you want to learn something about life, run a marathon.*
>
> — Emil Zátopek, four-time Olympic champion

Pursuing a PhD is like running a marathon. Or, should I say, an *ultra*-marathon. And you truly do learn something about life. There are ups and downs. Inspired at first, followed by a touch of despair and hopelessness as you start questioning the Meaning of Life. You have to discover the art it is to hurry slowly. Starting at a pace that will keep the cramps away – at least at an early stage (at the end it is often inevitable) – and then settle to that pace. As the race goes along, you come into a flow, where everything goes by itself. Automatically. By intuition. The mind and body disconnect. But then, then the pain reappears. At an instant, you hit the wall. You feel the pain streaming from your feet through your entire body. You feel exhausted, but yet so alive. It becomes a fight between yourself and the clock, knowing that the final food-service station approaches, longing for that moisture, home-baked chocolate cake that awaits there, keeping your motivation up, knowing that the PhD defence is coming somewhere in the future, like a finish-line sail at the end of the track.

***

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Great is victory, but the friendship of all is greater.

— Emil Zátopek, four-time Olympic champion

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My little anecdote of the link between doing a PhD and running a marathon may appear somewhat dubious, but there is indeed a more profound bond between my thesis and running. For, this thesis concerns topics of competitive firms. The etymological origin of the word "competition" is Latin "concurrere", put together by "con" (=with) and "currere" (=to run), meaning "running with". **Q.E.D.**

Closing the circle.

This thesis completes ten years of studies. I am grateful for having had the opportunity to study in depth some of my favourite topics. I hope you enjoy it as well.

Alver, June, 2023

Atle Haugen

Contents

Introduction

The rise of digital platforms and unanswered puzzles on vertical markets has brought forth new research questions in the research field of industrial organisation. Consumption of news, social networks and the purchasing of, e.g., groceries, increasingly take place on digital platforms, and digital platforms collect user data for the purpose of generating revenue through personal pricing or targeted advertising. At the same time, traditional, non-digital firms face fierce competition from global actors, who compete over the same eyeballs and consumer attention, leaving, e.g., the traditional newspaper publishers with fewer resources for investigative journalism.[1] Furthermore, the use of new, data-driven technologies may challenge consumer's privacy and fundamental democratic values; technological progress depends crucially on the incentives to innovate; and the practice of price discrimination in vertical wholesale markets may have significant impact on consumer welfare. All of this has implications for business models of firms, and the way in which firms compete, in a wide range of industries. Consequently, it is crucial to examine closer the dynamics of the competition and markets structures in these industries. This thesis addresses these topics, aiming to provide novel insights into the complexities of different markets.

Industrial organisation (IO) is "the study of the functioning of markets" (Tirole, 1988, p. 1). Building on the tradition of the Nobel laureate, Jean Tirole's (1988) seminal textbook on theoretical industrial organisation, it is necessary to understand the specific market characteristics for each particular market.[2] This includes the number of competing firms, firm strategies, pricing and business models. Furthermore, the competitive situation de-

[1] Online advertising is becoming an increasingly important and popular advertising platform for retailers. Since 2010, online advertising has increased by more than five times globally, whereas printed advertising revenue has fallen by one third (Wood, 2020).

[2] Belleflamme and Peitz (2015) provide a more recent, up-to-date contribution, which also includes rather new topics, such as platforms, network effects, and innovation economics; see also Belleflamme and Peitz (2021) for more on the economics of platforms. Tirole (2018) discusses aspects of the digital economy and democracy.

pends on the strategic action variables (e.g., consumer data, patents, prices), regulation (e.g., privacy, intellectual property, price regimes), and the nature of the market (e.g., horizontal, two-sided or vertical markets).

Hence, a study of IO problems can be used to answer important questions of interest and significance for how to organise the society, such as: (i) how to understand the digital (platform) economy, where data-driven business models challenge consumers' privacy; (ii) how to understand the way authorities may facilitate innovation, and at the same time secure that firms compete over the best technological solutions; and (iii) how to understand and identify the incentives and interests different market players have in wholesale markets.

This thesis attempts to shed light on some of these research questions, by using theoretical microeconomic analyses. The thesis consists of three self-contained essays on topics of industrial organisation: digital platforms, technology licensing and vertical markets. In addition, the fourth and final chapter provides an application to the teaching of such topics to business and economics students. Together, the four chapters contribute to a better understanding of the strategic interaction between competing firms in different markets, and to identify managerial implications and implications for both competition and innovation policy, consumer welfare and overall market outcomes.

The first two chapters concern competition among digital platforms. The first chapter studies the impact of targeting technologies, stricter privacy regulation, and consumer multi-homing on the strategic interactions between competing digital platforms, whereas the second chapter focuses on the market for innovation in the digital economy—more specifically, on technology licensing in markets with strong network effects. The third chapter revisits size-based wholesale price discrimination in a vertical market. In particular, the chapter analyses a supplier's incentives to price discriminate on wholesale prices or to commit to uniform pricing, and the welfare consequences for other market players (retailers and consumers) from the supplier's action. Whereas the first three chapters present novel research on digital platforms, technology licensing, and vertical markets, the final chapter presents two classroom experiments that can be used to teach such topics to business and economics students. The two classroom experiments stimulate to discussions on central topics of technology licensing and vertical markets. The first classroom experiment presents the problem of royalty stacking, which resembles the famous double-marginalisation problem in vertical markets—applied on innovation economics. The second experiment provides a remedy to the royalty-stacking problem: cross-licensing. The experiment reveals the anti-competitive effects of cross-licensing, highlighting the internal conflict of promoting innovation and promoting competition.

The thesis builds on contributions to the theoretical IO literature on two-sided platforms that emerged in the beginning of the 21st century (Rochet and Tirole, 2003; Armstrong, 2006), and more recent extensions more specifically related to digital platforms, such as multi-homing (Ambrus et al., 2016; Anderson et al., 2017; 2018; 2019; Athey et al., 2018), targeting (Athey and Gans, 2010; Crampes et al., 2009; Kim and Serfes, 2006), and privacy (Johnson, 2013; Kox et al, 2017). The thesis also builds on theoretical analyses of vertical markets and wholesale price discrimination (Katz, 1987; Inderst and Valletti, 2009; O'Brien, 2014; Akgün and Chioveanu, 2019), and contributes with more insight into understanding the incentives of the different market players in such markets. Finally, the thesis contributes to the rising pedagogical literature on pedagogical techniques in general (see, e.g., Biggs, Tang and Kennedy, 2022) and on economics instruction in particular (see, e.g., Emerson and English, 2016; and Picault, 2019). There is a growing attention (and demand from today's students) to make the central concepts of economics more applied and relevant to modern problems, in order to create a more engaging learning environment. The classroom experiments we present in the final chapter can motivate further discussions on related topics of business and economics.

All chapters treat problems that are on the agenda of policy makers. Policy enforcers, such as the EU Commission (Crémer et al., 2019), the US Federal Trade Commission (Scott Morton et al., 2019), the UK Digital Competition Expert Panel (Furman et al., 2019), the OECD (e.g., 2015; 2019; 2020; 2022) and both the French and German (2019), Portuguese (2019), Australian (2019), Nordic (2020) and UK (2020) competition authorities, have all addressed how to regulate digital platforms and promote innovation. Furthermore, both the European Commission's Digital Markets Act of 2022 and the five US anti-trust bills of 2021 propose new measures to regulate digital platforms (Bartz, 2021; Goodwin, 2021). So far, the literature has not analysed targeting in the context of two-sided multi-homing, despite its obvious relevance for data-driven media markets; and cross-licensing has not been studied in the context of two-sided platform markets (with strong network effects) despite digital, two-sided platforms being highly technology-intensive. Therefore, these two first chapters provide important insights and managerial and policy implications, with high relevance for the society since media markets are essential for well-functioning democracies.

Finally, size-based wholesale price discrimination has been a controversial antitrust issue dating back to the Robinson-Patman Act of 1936. The third chapter of this thesis sheds light on the underlying incentives of suppliers, retailers and consumers to price discriminate or to commit to uniform pricing, in a model where retailers have endogenous inside options.

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The thesis consists of four chapters on the industrial organisation of digital platforms and vertical markets. I briefly summarise them in the following paragraphs:

The first chapter is co-written with Charlotte Bjørnhaug Evensen. We address how competition between digital platforms is affected by important characteristics with digital markets, such as targeting technologies, stricter privacy regulation and consumer multi-homing. We analyse platforms that are financed by both advertising and subscription fees, and let them adopt a targeting technology with increasing performance in audience size: a larger audience generates more consumer data, which improves the platforms' targeting ability and allows them to extract more ad revenue. Targeting therefore increases the importance of attracting consumers. Previous literature has shown that this could result in fierce competition when consumers subscribe to only one platform (i.e., single-home). However, when we allow consumers to have multiple subscriptions (i.e., multi-home), we find that targeting softens the competition over consumers, which might imply that equilibrium profits are higher with targeting than without.

In the second chapter, I study the competitive effects of cross-licensing contracts between digital platforms. Generally, it is perceived as positive that cross-licensing facilitates the transfer of technology, which promotes innovation and competition. However, from one-sided markets, we know that there are potential anti-competitive effects, leading to higher consumer prices. In a two-sided model, I find another effect—the two-sided effect—that might alleviate the anti-competitive effects, and even flip the outcome. Indeed, prices might fall with a cross-licensing royalty fee due to the platform internalising cross-group network effects, to the benefit for consumers.

The third chapter is co-written with Charlotte Bjørnhaug Evensen, Øystein Foros and Hans Jarle Kind. We study the incentives of dominant suppliers to commit to uniform pricing in wholesale markets when inside options induce size-based wholesale price discrimination in favour of a large retailer. Seminal literature has provided clear-cut results: if it has the ability to do so, a dominant supplier will commit to uniform wholesale pricing, and consumers will be harmed. In a model with endogenous inside options, we show that the outcome is ambiguous depending on the degree of substitutability among the retailers. If the retailers are weak substitutes, the outcome flips around. Consumers are better off under uniform pricing, but the supplier has no incentives to commit to uniform pricing. Interestingly, for an intermediate level of substitutability, supplier and consumer interests can coincide.

The fourth and final chapter, is co-written with Steffen Juranek. We present two classroom experiments on technology licensing, which are intended to stimulate discussions of central concepts within industrial organisation and innovation, such as technology licensing, intellectual property rights, different royalty structures, patent pools and technology standards. The first classroom experiment introduces the concept of royalty stacking. Students learn that non-cooperative pricing of royalties for complementary intellectual property rights leads to a double-marginalisation effect. Cooperation solves the problem and is welfare-improving. The second classroom experiment introduces students to cross-licensing. It shows that reciprocal royalty payments dampen competition. We present the experimental procedures, and suggests routes for the discussion. For example, the experiments highlight the general tension of intellectual property and antitrust law: whereas intellectual property law aims to give innovation incentives with monopoly rights of a technology, antitrust law works against monopolies.

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Chapter 1

The impact of targeting technologies, privacy, and consumer multi-homing on digital platform competition

Chapter 1

The impact of targeting technologies, privacy, and consumer multi-homing on digital platform competition*

Charlotte Bjørnhaug Evensen and Atle Haugen

NHH Norwegian School of Economics

Abstract

We address the impact of targeting through the use of first-party data and consumer multi-homing on platform competition and market equilibria in two-sided markets. We analyze platforms that are financed by both advertising and subscription fees, and let them adopt a targeting technology with increasing performance in audience size: a larger audience generates more consumer data, which improves the platforms' targeting ability and allows them to extract more advertising revenue. Targeting therefore increases the importance of attracting consumers. Previous literature has shown that targeting could result in fierce price competition if consumers subscribe to only one platform (i.e., single-home). Surprisingly, we find that pure single-homing possibly does not constitute a subgame-perfect Nash equilibrium. Instead, platforms might rationally set prices that induce consumers to subscribe to more than one platform (i.e., multi-home). With multi-homing, a platform's audience size is not restricted by the number of subscribers on rival platforms. Hence, targeting softens the competition over consumers. We show that this result could imply that equilibrium profit is higher with than without targeting, in sharp contrast to the predictions given in previous literature.

Keywords: Two-sided markets, digital platforms, targeted advertising, privacy, incremental pricing, consumer multi-homing.

JEL classifications: D11, D21, L13, L82.

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Contact: Department of Economics, NHH Norwegian School of Economics, charlotte.evensen@nhh.no and Department of Business and Management Science, NHH Norwegian School of Economics, atle.haugen@nhh.no.

1.1 Introduction

In the digital era, media platforms collect personal data about their users on a large scale, and utilize this data to monetize on them. This strategy is widely used, and forms the core of digital media platforms' business models. For example, Netflix and Amazon use personal data to provide personalized product recommendations, and online newspaper platforms target advertising based on the consumers' online activities. Our focus is on the latter. By adopting advanced, programmatic advertising technologies such as targeting, the platforms can identify the consumers who are most prone to buying a given advertiser's product, and ensure that ad impressions are directed towards the most promising candidate buyers. A key feature of targeting algorithms is that they improve as they become exposed to more consumer data. Platforms that collect more user data could therefore be better equipped to connect advertisers with the target audience, and advertisers might be willing to pay more per impression on platforms with a large audience and higher targeting ability.[1]

At the same time, there is an increased demand for privacy. Until recently, such consumer data could easily be purchased by third parties. However, stricter privacy regulations, such as the General Data Privacy Regulation (GDPR) of 2018 or Apple's self-imposed App Tracking Transparency (ATT) policy of 2021, limit the scope of utilizing externally collected consumer information. Web browsers increasingly block third-party cookies, and platforms are moving away from third-party data and towards permission-based, internally collected first-party data (see, e.g., Goswami, 2020, and Walter, 2021). *The New York Times* and *The Washington Post*, for instance, have recently developed in-house solutions in order to control data and targeting (Fischer, 2020).[2] To target successfully, it is therefore as vital as ever for today's media platforms to attract consumer attention to their *own* platform. The aim of this study is to analyze how such targeting impacts digital platform competition. In particular, we will demonstrate how it is related to recent privacy regulations and consumer homing behavior.

[1]Goettler (2012) studies broadcast networks and provides empirical evidence that the ad price per viewer can increase with audience size.

[2]The VP of commercial technology and development at *The Washington Post*, Jarrod Dicker, stated in a press release that (Washington Post Press release, July 16, 2019): *"User privacy is paramount to us, so we are deeply invested in building sophisticated tools powered by first-party data."* The machine learning-based tools enable the newspaper to benefit from data on how users engage with the platform, and reduce reliance on cookie-driven information. The head of ad product for RED, Jeff Turner, elaborates (Washington Post Press release, July 16, 2019): *"Data points like a user's current page view and session on The Post's site are much more relevant to that user's current consumption intention than the information a cookie-driven strategy can offer."* Advertisers cannot find this insight elsewhere, which gives the platforms a competitive advantage. The focus on privacy has increased the strategic importance of first-party data, which is also the key to successful targeting in our model.

Previous studies on digital media markets have shown that targeting can increase competition and benefit consumers through lower subscription prices (see, e.g., Kox et al., 2017; Crampes et al., 2009).[3] However, the additional revenue from the ad side of the market is competed away on the consumer side of the market, leaving the platforms worse off. As Kox et al. (2017) point out, although it would be in the platforms' common interest not to target ads, each platform might have individual incentives to do so. This suggests that the platforms would like to avoid targeting. However, this prediction is not in line with the observation that digital platforms profitably target ads.

Common to these studies is the stark assumption that consumers single-home (i.e., join only a single platform). In practice, we observe that while some consumers are indeed devoted to a single media provider, others spread their attention across multiple platforms.[4] The emergence of digital technologies, with extremely low online distribution and print costs, has facilitated the latter, which we refer to as consumer multi-homing. All it takes to read an additional newspaper online is a few extra clicks.[5] By relaxing the assumption of single-homing, we find that targeting might be profitable to the platform, but only if multi-homers are sufficiently valued in the ad market.

The main mechanism that drives this result is a strategic substitutability induced by a platform's ability to affect the composition of a rival platform's total demand. To see why, note first that the distinction between exclusive (single-homing) and non-exclusive (multi-homing) consumers is essential for ad-financed platforms. When consumers single-home, the platform acts as a gatekeeper: Having exclusive access to certain consumers implies that advertisers cannot reach them elsewhere, allowing the platforms to price their ad space accordingly. Consumers who are shared with other platforms, on the other hand, are typically worth less in the ad market. Since the advertisers can reach these consumers on other platforms as well, the platforms can only charge advertisers the incremental value of an additional impression. This is known as the incremental pricing principle (see, e.g., Ambrus et al., 2016; Athey et al., 2018, and Anderson et al., 2018), and implies that since a platform could—by changing its own price—affect the composition of the rival's demand, it can thereby also affect the value the rival can obtain in the ad

[3]Kox et al. (2017) explicitly examine targeting, while Crampes et al. (2009) consider a more general advertising technology.

[4]This has caught the attention of a number of researchers, such as Ambrus et al. (2016), Athey et al. (2018), and Anderson et al. (2017; 2018; 2019).

[5]Gentzkow and Shapiro (2011), Gentzkow et al. (2014), and Affeldt et al. (2021) provide additional arguments as to why digital technologies make multi-homing more compelling. For example, Gentzkow et al. (2014) show that 86 percent of the circulation of entrants to the US newspaper market comes from households reading multiple newspapers. Furthermore, Liu et al. (2021) provide a number of examples of industries where multi-homing becomes more prominent.

market from its consumer mass. This, in turn, changes the strategic interaction.

To analyze formally the impact of targeting for a digital platform's business model, we implement targeting into a two-sided framework. We set up a three-stage model, in which the platforms decide whether to target at the first stage, and choose subscription and advertising prices at the second stage. At the final stage, the consumers decide how many subscriptions to buy (i.e., to single-home or multi-home). We search for a subgame-perfect Nash equilibrium. We incorporate that the performance of the targeting technology increases with the amount of data, by imposing a targeting technology with increasing returns to scale in the audience size. Targeting thus increases the importance of attracting consumers.

In line with existing literature, we find that targeting generates a prisoner's dilemma situation if consumers single-home. Remarkably, however, we also find that platforms may not want to set subscription prices that makes consumers prefer single-homing. Setting prices that incentivize consumers to multi-home could as such be a unique equilibrium.

Combining elements from Crampes et al. (2009), Ambrus et al. (2016), and Anderson et al. (2017), we show that the outcome is quite different if consumers multi-home. It is known from the literature (Kim and Serfes, 2006; Anderson et al., 2017) that the incremental pricing principle implies that prices are strategically independent if consumers multi-home: if one platform changes its price, this has no impact on a rival platform's optimal price setting. Our results confirm this result in the absence of targeting. More specifically, suppose that you are going to purchase *The Washington Post* and are considering buying a copy of *The New York Times* as well. When deciding whether to purchase *The New York Times* as an additional newspaper, what matters for the consumer is the price of *The New York Times* (and not *The Washington Post*). Prices are therefore strategically independent.

In this paper, we introduce targeting, and find that it has surprising consequences for the strategic interaction among digital platforms. In particular, the strategic dependence is restored, but interestingly, we find that prices become strategic substitutes: it is less profitable for a platform to reduce its subscription price if rival platforms do the same. To understand the intuition behind this result, we must realize that although the consumer's purchasing decision does not change when we introduce targeting, the platform's considerations do. For the consumer, the price of *The Washington Post* is still irrelevant when considering the incremental utility of purchasing *The New York Times* in addition to *The Washington Post*. However, when platforms target ads, the platforms must now take into account that the price setting of rival platforms will affect the profitability of targeting. If we revert to our previous example, by reducing its subscription price, *The New York Times* could improve its targeting ability and charge advertisers more. Since advertisers are not willing to pay the full additional cost for non-exclusive consumers (recall the incremental pricing principle), such a price reduction would be more attractive the larger the number of exclusive consumers. A price reduction by its rival, *The Washington Post*, would, however, increase the number of consumers that buy *The Washington Post* in addition to *The New York Times*. *The New York Times*'s gain from its increased targeting ability would therefore be counteracted by a greater fraction of non-exclusive consumers, with less value in the ad market. The ad market therefore becomes relatively less important for *The New York Times*, and they would raise subscription prices instead (as a response to *The Washington Post*'s price reduction). Hence, subscription prices become strategic substitutes.

Although offering targeted advertising still makes it optimal for the platform to reduce subscription prices when consumers multi-home, it does not trigger an aggressive response from rival platforms. As a result, it is more imperative to implement targeting. Yet, softer competition alone cannot ensure that targeting is profitable. We show that this can only be guaranteed if multi-homing consumers are sufficiently valuable to advertisers.

Finally, we model media platforms that raise revenue from selling both subscriptions and advertising space. The growth of data-driven, targeted advertising has completely changed the media—and in particular the newspaper—industry. This has happened for two reasons. First, there has been a shift from printed to digital advertising. Worldwide, online ad expenditure has increased by more than five times since 2010, whereas printed advertising has fallen by one third (Wood, 2020). Second, the ad market has become global. Local newspapers face fierce competition from global media platforms, such as Facebook and Google, with the consequence that local newspaper publishers have been unable to recoup the lost printed ad revenue with digital ads. To illustrate, total advertising revenue in the US newspaper industry fell from $26 billion in 2010 to $16 billion in 2017 (Pew Research Center, 2018). Consequently, local newspaper publishers have lost a substantial share of their ad revenue, and, instead, become more dependent on raising subscription revenue—in addition to financing from advertising.[6] There is simply not enough revenue potential on either side of the market.

Outline. The paper proceeds as follows. In Section 1.2, we review related literature. In Section 1.3, we present the basic model and introduce a targeting technology, before comparing our results to disclose when targeting is profitable. In Section 1.4, we compare potential equilibria, and search for the Nash equilibrium, before concluding in Section 1.5.

[6]For example, The *New York Times* successfully shifted to a digital subscription paywall strategy in 2011; see Chung et al. (2019) who provide an overview of the development of digital paywalls.

1.2 Related literature

This paper draws on two strands of the media literature that are not usually brought together. One strand investigates the impact of targeted advertising, and the other examines the importance of consumer multi-homing.

Athey and Gans (2010) and Bergemann and Bonatti (2011) were among the first to address the impact of targeting on media platform competition. The former paper considers competition between a local platform tailored to the local audience (which is the local advertiser's intended audience) and a general platform that depends on targeting technologies to identify the advertiser's relevant consumer base, while Bergemann and Bonatti (2011) model competition between online and offline media under the assumption that online media has a higher targeting ability. A common feature of both papers is that platform differences are exogenously given. This gives rise to significant effects on the supply and demand of ads, which would be less prominent in a model with symmetric platforms (such as ours). In this paper, we disregard the allocative effects, and allow the targeting ability to be determined within the model: by reducing its subscription price, a platform can increase its audience size and improve its targeting ability. Since neither of the above-mentioned papers regards subscription fees, a similar interplay between the two sides of the market does not occur in these papers. This is one explanation for why we arrive at notably different results.

Another explanation is related to the targeting technology specification itself. In the notion of Hagiu and Wright (2021), we implement a targeting function of across-user data learning. The more data the technology is fed, the better the targeting technology performs. A general form of our targeting specification can be recognized in Crampes et al. (2009), who demonstrate that the nature of the advertising technology is decisive for platform behavior and market outcomes. They model the impact of advertising technologies with constant, decreasing, and increasing returns to scale in the audience size, and point at the limitation of assuming linearity. Although the authors do not accentuate increasing returns to scale, we argue that the current focus on first-party data and technology makes this particular specification highly relevant. We therefore use a variant of this technology in our set-up. Like most previous research on targeting and media platform competition, Crampes et al. (2009) assume consumer single-homing. We relax this assumption and show that by allowing for multi-homing, we obtain entirely different outcomes.

This leads us to the next point: This paper adds to the growing literature on consumer multi-homing. Seminal works on multi-homing (Ambrus et al., 2016, and Anderson et al., 2018) have shown that multi-homing strongly affects the results in two-sided market analyses, and find that prices are strategically independent. A key take away from existing research is the incremental pricing principle that we describe in the Introduction. The incremental pricing principle follows from the insight that multi-homing consumers are less worth than single-homers. As pointed out by Athey et al. (2018), impressing the same consumer twice is less efficient than impressing two different consumers. Ambrus et al. (2016) emphasize that one implication of advertisers' lower valuation of multi-homing consumers is that it is not only the overall demand that counts—the *composition* of the demand also matters. When advertisers place ads on platforms with multi-homing consumers, there is a risk that some consumers will have seen the ad before. We share this insight of consumer multi-homing and ad-financed platform markets, and combine this with elements from the user-financed platform market in Anderson et al. (2017) to derive a two-sided model with dual source financing. We find that by implementing a targeting technology that has increasing returns to scale in audience size, a change in the composition of the demand also changes the value of the consumer mass that a platform can collect in the ad market. Therefore, targeting restores a strategic dependence, and prices become strategic substitutes.

The main mechanism for our results in this paper is a strategic substitutability of subscriptions prices, and thereby of business models (i.e., financing source), when multi-homing takes place. A similar result is found by Calvano and Polo (2020), who propose a model with competing broadcasters and endogenous differentiation in business models. They find an asymmetric equilibrium in which one platform is fully financed by ads and the other by subscriptions. The mechanisms at play are similar to our model. Also we find that it is optimal for one platform to move towards subscription financing if the other platform moves towards ad financing. However, due to our targeting specification, the ad price does not necessarily decrease with the number of non-exclusive consumers. Attracting more consumers increases the ad price. As such, we do not get the asymmetric equilibrium of Calvano and Polo (2020). Moreover, as Calvano and Polo stress, to end up with an asymmetric equilibrium, there must be revenue potential on both sides of the market, which—as argued in the final paragraph of the Introduction—does not hold for the types of media platform markets included in the scope of our analysis.

In recent works, Haan et al. (2021) and Athey and Scott Morton (2021) argue that platforms can benefit from engaging in strategies that lead to head-on competition for consumers, e.g., by stimulating less consumer multi-homing behavior in order to create more market power in the ad market, and deprive rivals of scale economies and network effects in the long run. We, on the contrary, find that the platforms do want to attract more consumers (e.g., by attracting more multi-homers), since multi-homers—although less valuable in the ad market—are vital to the ability to target (as it increases the total audience).

Although various papers assess different aspects of consumer multi-homing, the literature that integrates multi-homing with targeted advertising is scarce. There are, however, a few exceptions. Taylor (2012) investigates how targeting affects platforms' incentives to improve content in order to increase their share of consumer attention, with a focus on how they can retain this attention. In contrast, we disregard the attention span of the audience and rather focus on its size. Another exception is D'Annunzio and Russo (2020; 2023), who study the role of ad network intermediaries and how tracking technologies affect market outcomes. However, since they focus on a different part of the industry (ad networks), they address other and complementary questions.

Finally, this paper also relates to current discussions on privacy. The use of consumer data to target ads has raised privacy concerns. Johnson (2013) stresses that targeting might be harmful when consumers value privacy. He investigates the impact of targeting when consumers have access to ad-avoidance tools, and shows that consumers tend to block too few ads in equilibrium. Kox et al. (2017) incorporate privacy considerations in a work that is closer to ours. In a similar framework, the authors show that targeting reduces consumer welfare if the disutility of sharing personal information is greater than the advantage of lower subscription prices. Recall from the Introduction that Kox et al. (2017) also find that platform profits decrease with targeting. As a result, their model suggests that stricter privacy regulations benefit both consumers and platforms. An important difference between Kox et al. (2017) and this paper is that the former assumes a linear advertising technology and consumer single-homing.

More recently, Gong et al. (2019) proposed a different approach in which competition for consumers plays a prominent role. In their model, differences in the platforms' ability to target ads are exogenously given.[7] Assuming that consumers dislike irrelevant ads, Gong et al. (2019) suggest that improved targeting reduces the consumers' nuisance costs. At the same time, greater targeting ability attracts more advertisers. Hence, platforms with superior targeting abilities attract more consumers and advertisers, and are thus more profitable.

1.3 The model

We consider two media platforms that offer subscriptions to consumers and advertising space (eyeballs) to advertisers. We employ a simple Hotelling (1929) model with a line of length *one*, and assign one platform to each endpoint, i.e., platform 1 is located at $x_1 = 0$ and platform 2 is located at $x_2 = 1$. Along the line, there is a unit mass of uniformly distributed consumers. The

[7] In an extension, Gong et al. (2019) allow the platforms to invest in targeting ability, and show that under-investment is most likely to occur.

distribution represents the consumers' tastes: the greater the distance to a platform, the greater the mismatch between the consumer preferences and the platform characteristics.

We consider two different homing regimes (which we later analyze whether constitute Nash equilibria). First, in the pure single-homing regime (hereafter referred to as the single-homing regime) all consumers subscribe to only one platform. Second, we consider a multi-homing regime where some (but not all) consumers use more than one platform.[8] In addition, we consider two different advertising technologies: Either the platform is able to acquire a targeting technology that can target consumers or the platform does not acquire any targeting technology.

Timing. The timing is as follows:
Stage 1: Each platform decides whether to acquire a targeting technology or not.
Stage 2: Each platform simultaneously announces its advertising and subscription prices, and competes for advertisers and consumers.
Stage 3: Consumers decide how many subscriptions to buy (i.e., whether to single- or multi-home).

We are looking for a subgame-perfect Nash equilibrium.

1.3.1 Consumer demand

Consumers choose endogenously how many platforms to join. A single-homing consumer only joins the one platform they prefer the most. Let u_i represent the utility a consumer located at x obtains from subscribing to platform $i = 1, 2$:

$$u_i = v - t|x - x_i| - p_i. \tag{1.1}$$

The parameter $v > 0$ is the intrinsic utility of joining a platform, $t > 0$ represents the disutility of the mismatch between the consumer's preferences and the platform's characteristics, and p_i is the subscription price.

However, we also allow consumers to subscribe to both platforms (i.e., multi-homing). The utility from dual subscription equals the sum of the individual utilities:[9]

[8] If all consumers multi-home, targeting would neither affect demand nor subscription prices. In this case, the analysis simply boils down to the change in ad prices.

[9] If a consumer has two subscriptions, the total utility is not necessarily the entire sum of the individual utilities. For example, there is often some content overlap if the consumer reads two newspapers. We can therefore reformulate $u_{12} = (1 + \theta)v - t - p_1 - p_2$, where $\theta \in (0, 1)$. This will put stricter restrictions on t (see Sections 1.3.5 and 1.4), but our results concerning profitability and the Nash equilibrium are robust to this overlap. For ease of reading, we will therefore assume that dual subscription simply equals the sum of the individual utilities.

$$u_{12} = 2v - t - p_1 - p_2. \tag{1.2}$$

If the incremental utility of multi-homing is positive for some consumers, $u_{12}(x) \geq u_i(x)$, those consumers will subscribe to both platforms. Hence, each platform potentially serves two groups of consumers: exclusive subscribers and non-exclusive subscribers who are shared with the rival platform.

Let x_{12} represent the location of the consumer who is indifferent between subscribing to just platform 1 and subscribing to both platform 1 and platform 2.[10] Since platform 2 does not provide any additional utility to the indifferent consumer, $u_{12} = u_1$. As such, platform 1's exclusive demand arises from consumers who are located to the left of x_{12}. It follows that the platforms' non-exclusive demand is thus comprised of the consumers located between x_{12} and x_{21}. This is illustrated in Figure 1.1.

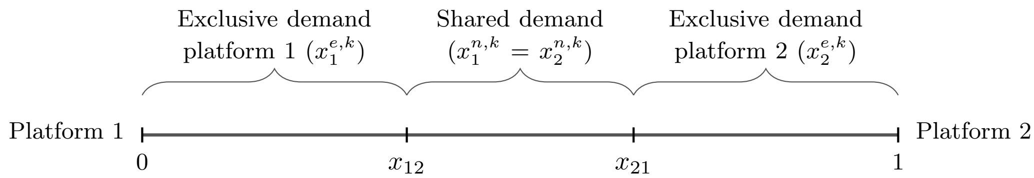

Figure 1.1: Demand platform $i = 1, 2$.

We solve $u_{12} = u_1$ and $u_{12} = u_2$, and find $x_{12} = \frac{1}{t}\left(-v + t + p_2\right)$ and $x_{21} = \frac{1}{t}(v - p_1)$, respectively. With symmetric platforms, we can see that platform i's exclusive demand (superscript 'e' for exclusive and 'M' for multi-homing regime) is given by

$$x_i^{e,M} = \frac{-v + t + p_j}{t}, \tag{1.3}$$

whereas its non-exclusive demand (superscript 'n' for non-exclusive and 'M' for multi-homing regime) equals

$$x_i^{n,M} = \frac{2v - t - p_i - p_j}{t}. \tag{1.4}$$

Total demand is the sum of exclusive and non-exclusive demand:

$$D_i^M = x_i^{e,M} + x_i^{n,M} = \frac{v - p_i}{t}. \tag{1.5}$$

[10] Vice versa, x_{21} represents the location of the consumer who is indifferent between subscribing to only platform 2 and both platform 2 and platform 1.

Equation (1.5) tells us that total demand for platform i is independent of the rival platform's subscription price (p_j). A change in p_j, however, will affect the composition of platform i's demand. From Equation (1.3), we see that the number of exclusive subscribers is increasing in p_j, while Equation (1.4) shows an inverse relationship between the number of non-exclusive subscribers and p_j.

If all consumers only join one platform, i.e., single-home, then $x_i^{n,S} = 0$. The consumer who is indifferent between only subscribing to platform 1 and only subscribing to platform 2 is located at $\widetilde{x}$, where $u_1 = u_2$. Consumers to the left of $\widetilde{x}$ subscribe to platform 1 and consumers to the right subscribe to platform 2. Hence, the demand function (superscript 'S' for single-homing regime) equals:

$$D_i^S = x_i^{e,S} = \frac{1}{2} + \frac{p_j - p_i}{2t}. \tag{1.6}$$

1.3.2 Advertisers and Platforms

Turning to the advertising side, we normalize the number of advertisers to *one*. The demand for ads is perfectly elastic, and we assume that each advertiser purchases space for one ad per platform. We thus consider a single advertiser that needs to advertise its products or services to consumers in order to sell them. For each unit sale, the advertiser earns a fixed payoff, which we normalize to one. No consumer wants to buy more than one unit, but must observe an ad from this advertiser before purchasing the product. With probability $\alpha \leq 1$, a consumer will observe the ad they are exposed to. Given these assumptions, the advertiser's willingness to pay to advertise to an exclusive consumer is α. In line with the principle of incremental pricing (see Anderson et al., 2018), we assume that the advertisers are willing to pay α_i to reach an exclusive consumer on platform i, but only a fraction $\sigma\alpha_i$ to reach a non-exclusive consumer on platform i, conditional on (already) advertising to this consumer on platform j, where $\sigma \in (0, 1)$.[11] This set-up corresponds to Anderson et al. (2018).

We consider a game in which each platform simultaneously announces its advertising prices,

[11] Our specification of $\sigma \in (0, 1)$ follows the idea of Athey et al. (2018) that there are decreasing returns to scale to duplicate ad impressions with the same consumer, and that this reflects the market power of accessing consumers. In an empirical study of US magazines, Shi (2016) finds that non-exclusive consumers are about half as valuable as exclusive consumers, i.e., $\sigma = \frac{1}{2}$. This estimate indicates that it is reasonable to assume that platforms charge less for consumers who can be reached elsewhere. Re-targeting across platforms (i.e., $\sigma > 1$) is only relevant if the advertiser is able to track the consumer (through a third-party cookie) from one platform to another. In this case, the advertiser needs to advertise through an independent ad network service. This is not within the scope of our analysis, however. We want to shed light on the strategy of media platforms that build their business model on targeting based on data about their own consumers, i.e., on first-party data (being their own ad network).

and where the platforms can charge different advertising prices depending on whether a consumer is exclusive or shared. It follows that platform i's ad revenue can be defined as

$$A_i^k = \alpha_i^k x_i^{e,k} + \sigma \alpha_i^k x_i^{n,k}, \tag{1.7}$$

where superscripts $k = \{S, M\}$ denote the single-homing regime and the multi-homing regime, respectively.

Total profit is given by[12]

$$\pi_i^k = p_i^k D_i^k + \alpha_i^k \left(x_i^{e,k} + \sigma x_i^{n,k} \right). \tag{1.8}$$

1.3.3 No targeting

Consider first a model without targeting. In this situation, we assume that the advertiser's value from reaching a consumer is not platform dependent, such that $\alpha_i^k = \alpha_j^k = \alpha$. We differentiate Equation (1.8) and find the first-order condition

$$\frac{\partial \pi_i^k}{\partial p_i^k} = \left[D_i^k + \frac{\partial D_i^k}{\partial p_i^k} p_i^k \right] + \left[\alpha \left(\frac{\partial x_i^{e,k}}{\partial p_i^k} + \sigma \frac{\partial x_i^{n,k}}{\partial p_i^k} \right) \right] = 0. \tag{1.9}$$

The first square bracket on the right-hand side of Equation (1.9) deals with the consumer side of the market, corresponding to a standard one-sided model. If we consider an increase in p_i, this implies that each consumer pays more, but also entails a lower number of subscribers. In our two-sided model, the price increase has an impact on the ad side of the market as well: platform i displays fewer ads and thereby loses ad revenue. This is captured by the second square bracket. Because of the negative effect of a price increase on ad revenue, the optimal subscription price is lower in a two-sided model.

We next investigate the strategic interaction of the subscription prices, and find:

Lemma 1.1 *(No targeting) Subscription prices are*

(i) strategic complements in the single-homing regime

(ii) strategically independent in the multi-homing regime.

Proof. Solving Equation (1.9) for p_i^k gives the best-response functions:

$$p_i^M(p_j) = \frac{v - \sigma\alpha}{2} \text{ and } p_i^S(p_j) = \frac{t + p_j - \alpha}{2}. \tag{1.10}$$

[12] We set all costs to zero to simplify the model.

Taking the partial derivatives of the best-response functions in (1.10) with respect to p_j, it follows directly that (i) $\partial p_i^S(p_j)/\partial p_j > 0$ and (ii) $\partial p_i^M(p_j)/\partial p_j = 0$. ■

It follows from Equation (1.10) that subscription prices are strategically independent in the multi-homing regime. In other words, platform i's subscription price is not responsive to changes in platform j's subscription price. This result is in line with seminal work on multi-homing (Ambrus et al., 2016, Anderson et al., 2018), which has demonstrated that multi-homing strongly affects the results in two-sided markets. To see why, suppose that platform j adjusts p_j. From Section 1.3.1, we know that even though it alters the number of exclusive and non-exclusive consumers, the price change has no effect on platform i's total demand. This is because the location of platform i's marginal consumer remains the same. Keep in mind that the marginal consumer is located where their incremental value of subscribing to platform i is zero. Hence, platform i's subscription price still extracts the marginal consumer's incremental benefit. Besides, platform i's price setting does not affect the advertiser's valuation of the marginal consumer. Consequently, platform i has no incentive to change its subscription price in response to an adjustment in p_j. In the single-homing regime, we are left with the standard result that prices are strategic complements.

1.3.4 Introducing targeting

Next, we introduce targeting to our model. We acknowledge that advertisers may not only care about the reach of ads, but also about the quality of the match with the audience. Suppose that the platforms implement targeting technologies that enable them to create better matches between advertisers and viewers. We assume that advertisers are willing to pay for improvements in the platforms' targeting ability, and formulate the ad price as follows:

$$\alpha_i^k = \alpha(1 + \mathbb{1} D_i^k), \tag{1.11}$$

where $\mathbb{1}$ is a dummy that takes on the value *one* when targeting is included in the model and *zero* otherwise. Notice that in the latter case, Equation (1.11) reverts to the non-targeting ad price (α). For $\mathbb{1}$ equal to *one*, the definition implies that the ad price increases with the platform's audience size ($\frac{\partial \alpha_i^k}{\partial D_i^k} > 0$), capturing the benefit of having more consumer data on the platform, and, hence, improved targeting ability.

The targeting function in Equation (1.11) holds two important properties: (1) across-user data-enabled learning, and (2) first-party data. Using the notion of Hagiu and Wright (2021), across-user data-enabled learning implies that targeting ability increases with the total input of data, i.e., the total number of users platform i attracts (D_i^k).[13] For example, the platform can divide consumers into groups by age, gender, or other characteristics, and target a user based not only on the data it holds on that specific user, but also based on information about other users.[14] The technology thereby becomes more accurate as the platforms increase their audience size and, in turn, generate more data.

Moreover, our targeting specification also captures recent developments in privacy regulation. In particular, concerns about abuse of third-party data has resulted in new privacy regulations, such as the GDPR in the EU and corresponding privacy acts in several US states (e.g., California Consumer Privacy Act, CCPA). Third-party data are typically collected by 'cookies', which consumers come across everywhere online. Via third-party cookies, the platform does not need to own the data itself, but can buy access to them. However, the increasingly more stringent privacy regulations limit the scope of third-party cookies. To illustrate, online newspaper publishers, such as *Vox Media*, *The New York Times*, and *The Washington Post*, all have removed third-party cookies from their platform, and now build their own first-party data-based advertising technologies (Davies, 2019; Fischer, 2019; 2020).[15] This means that the platform must own the data it uses for targeting purposes.

Inserting Equation (1.11) into Equation (1.8), and differentiating with respect to own price, we find the new first-order condition:

$$\frac{\partial \pi_i^k}{\partial p_i^k} = D_i^k + \frac{\partial D_i^k}{\partial p_i^k} p_i^k + \alpha(1 + \mathbb{1} D_i^k) \left(\frac{\partial x_i^{e,k}}{\partial p_i^k} + \sigma \frac{\partial x_i^{n,k}}{\partial p_i^k} \right) + \mathbb{1} \frac{\partial \alpha_i^k}{\partial p_i^k} \left(x_i^{e,k} + \sigma x_i^{n,k} \right) = 0. \tag{1.12}$$

When $\mathbb{1}$ equals *zero*, we recognize Equation (1.12) as the first-order condition in the model without targeting (cf. Equation (1.9)). The two additional terms that appear when $\mathbb{1}$ equals *one* represent the effects that emerge when we incorporate targeting. First, consider the third term on the right-hand side. This tells us that ad revenue is more sensitive to changes in the number of ad impressions (in response to a change in the subscription price) than is the case without targeting.[16] The explanation is that the ad price—which corresponds to the first part of the third term (cf. Equation (1.11))—is higher with targeting ($\mathbb{1} = 1$). Second, we evaluate the fourth

[13]We assume that each consumer delivers one data point, such that we measure the amount of data by the number of consumers.

[14]See Hagiu and Wright (2021) for further discussions on different types of data-enabled learning.

[15]Moreover, Apple's web browser Safari and Mozilla's Firefox have already disabled third-party cookies, whereas Google plans to replace their cookies with an aggregated 'Sandbox tool', containing anonymous, aggregated consumer data, by the second half of 2024 (O'Reilly, 2020; Chavez, 2022).

[16]Since the ad makes an impression on each consumer once, the number of subscribers is equivalent to the number of ad impressions.

term. This expression captures a property that is not present in the model without targeting, namely that a platform's ad price responds to changes in its own subscription price. An increase in p_i^k causes a reduction in α_i^k, and vice versa.

Solving Equation (1.12) for p_i^k, we find the best-response functions:

$$p_i^M(p_j) = \frac{v(t+\alpha) - \alpha(t+3v\sigma) - \alpha p_j(1-\sigma)}{2(t-\alpha\sigma)} \text{ and } p_i^S(p_j) = \frac{t(t-2\alpha) + p_j(t-\alpha)}{2t-\alpha}. \quad (1.13)$$

The best-response functions reveal a striking difference between the single-homing regime and the multi-homing regime. If all consumers single-home, subscription prices are strategic complements ($dp_i^S/dp_j > 0$). In contrast, if at least some consumers multi-home, subscription prices are strategic substitutes ($dp_i^M/dp_j < 0$). This means that the optimal response to changes in the rival platform's subscription price depends on whether consumers only single-home or whether some of them multi-home.

We can summarize the above discussion in the following proposition:

Proposition 1.1 *(Targeting) When platforms target ads, subscription prices are*

(i) strategic complements in the single-homing regime

(ii) strategic substitutes in the multi-homing regime.

Proof. By differentiating Equation (1.13), it follows directly that (i) $\frac{\partial p_i^S(p_j)}{\partial p_j} = \frac{t-\alpha}{2t-\alpha} > 0$ and (ii) $\frac{\partial p_i^M(p_j)}{\partial p_j} = -\frac{\alpha(1-\sigma)}{2(t-\alpha\sigma)} < 0$. ■

The first result in Proposition 1.1 is well known in the literature (see, e.g., Crampes et al., 2009; Kox et al., 2017): In a single-homing regime, the best response to a change in the rival subscription price is to adjust one's own price in the same direction.

The second result in Proposition 1.1, however, is quite surprising. While platform i's best response to a change in the rival subscription price is to do nothing in the multi-homing model without targeting (cf. the second result of Lemma 1.1), the best response in the targeting model is to adjust p_i^M in the opposite direction. Since targeting does not change the property of total demand being independent of the rival subscription price, the difference between the models may not be immediately intuitive. After all, this property implies that p_i^M extracts the marginal consumer's incremental benefit regardless of any changes in p_j^M. The key to understanding why a change in p_j^M still induces a response is that targeting enables platform i to affect the advertisers' willingness to pay. To see why, suppose that platform j increases p_j^M. This creates a shift from non-exclusive to exclusive subscribers for platform i, which implies a smaller share of discounted ad impressions. Platform i would therefore gain from increasing its ad price. Targeting enables the platform to do so by reducing p_i^M and improving its targeting ability. Conversely, a reduction in p_j^M provides incentives to increase p_i^M.

1.3.5 When is targeting profitable?

In this section, we compare the outcomes with and without targeting, and reveal when targeting is profitable. First, we find the symmetric non-targeting equilibrium prices. Solving the best-response functions in Equation (1.10) simultaneously, we have

$$p^{M,NT} = \frac{v - \sigma\alpha}{2} \text{ and } p^{S,NT} = t - \alpha, \tag{1.14}$$

where superscript 'NT' denotes the non-targeting equilibrium.

We then find the symmetric targeting equilibrium prices (superscript 'T' denotes the targeting equilibrium) by solving the best-response functions in Equation (1.13) simultaneously:

$$p^{M,T} = \frac{v\,(t+\alpha) - \alpha\,(t + 3v\sigma)}{2t + \alpha(1 - 3\sigma)} \text{ and } p^{S,T} = t - 2\alpha. \tag{1.15}$$

Comparing Equations (1.14) and (1.15) allows us to state the following:

Lemma 1.2 *Subscription prices are lower when platforms use targeting technologies.*

Proof. See Appendix. ■

The result of Lemma 1.2 showing that subscription prices are lower when platforms target ads, holds irrespective of whether all consumers single-home or whether some choose to multi-home.

Targeting provides greater incentives to attract a larger audience, and to do so, the platforms lower their subscription prices. The effect of this price reduction on profits depends on the strategic response that follows in each regime. We go on to first analyze the single-homing regime, then proceed to the multi-homing regime.

Single-homing

We restrict our attention to markets with full coverage and endogenously non-negative prices. This, as well as fulfillment of the stability and second-order conditions, is ensured by Condition 1.1:

Condition 1.1 *(Single-homing)* $\frac{5}{2}\alpha < t < \frac{2}{3}(v + \alpha)$.

It follows from Lemma 1.2 and Proposition 1.1 that targeting leads to fiercer price competition when all consumers single-home. The symmetric equilibrium demand is equivalent with and without targeting:

$$D^{S,T} = D^{S,NT} = \frac{1}{2}. \tag{1.16}$$

It thus follows that the subscription revenue is lower with targeting. Even though ad revenue is higher, it does not fully compensate for the lost subscription revenue. Inserting (1.14), (1.15) and (1.16) into (1.8), we find the equilibrium profits with and without targeting, respectively, to be:

$$\pi^{S,T} = \frac{t}{2} - \frac{\alpha}{4} \text{ and } \pi^{S,NT} = \frac{t}{2}. \tag{1.17}$$

Equation (1.17) clearly shows that the targeting profit is lower than non-targeting profit and decreases with the technology's sensitivity to more data. The reason is that the higher the α, the greater the incentive to reduce the subscription price, which significantly reduces subscription revenue. This raises the question of whether the platforms would at all wish to adopt targeting technologies. Although it is in the platforms' common interest not to target, each platform has incentives to deviate from the mutually beneficial strategy. The platforms might therefore end up in a prisoner's dilemma situation where all platforms target (see also Kox et al., 2017).

We therefore propose the following lemma:

Lemma 1.3 *(Prisoner's dilemma) When all consumers single-home, targeting is a dominant strategy and the platforms end up in a prisoner's dilemma.*

Proof. See Appendix. ■

As demonstrated in the equilibrium analysis, the platforms could, however, be better off by setting the multi-homing price and also attracting consumers who already subscribe to the rival platform.

Multi-homing

Assume now consumer multi-homing. The consumer chooses independently which platform(s) they will subscribe to when facing the prices from each platform. We consider partial multi-homing, i.e., situations where some, but not all, consumers use both platforms. Note that $t > \frac{1}{2}(v + 3\sigma\alpha)$ and $t < v + \sigma\alpha$ ensure the existence of exclusive and non-exclusive consumers, respectively. Moreover, we confine the analysis to situations with endogenously non-negative subscription prices and parameter values that satisfy all second-order and stability constraints. The conditions are given in Appendix A.1.

Proposition 1.2 *(Multi-homing) Suppose that the multi-homing conditions hold. Targeting is profitable in the multi-homing equilibrium if advertisers place a high enough value on non-exclusive consumers. Targeting is then a dominant strategy. A sufficient condition is* $\sigma > \frac{1}{3}$*.*

Proof. See Appendix. ■

Proposition 1.2 contains two important results. First, we argue that targeting is a dominant strategy. The platforms will always have an incentive to target ads, irrespective of the strategic actions of the rival platform. The second result might prevent the platforms from ending up in a prisoner's dilemma situation (as in the single-homing regime). The first thing to note is that it follows from Lemma 1.2 and Proposition 1.1 that targeting provides incentives to reduce the subscription price, and that the rival platform will respond favorably. Moreover, the incentive to lower the price increases with advertisers' willingness to pay for non-exclusive consumers. This is captured in our model by the σ-parameter, where $\partial p^{M,T}/\partial\sigma < 0$. Despite the price reduction contributing to greater overall demand, and the increase being reinforced by the rival platform's response, we nonetheless find that the equilibrium subscription revenue is lower with targeting ($p^{M,T}D^{M,T} < p^{M,NT}D^{M,NT}$).

For targeting to be profitable, two conditions must therefore be satisfied: (i) Ad revenue must increase with targeting; and (ii) the increase in ad revenue must be greater than the loss in subscription revenue. Comparing ad revenue with and without targeting, we find in Proposition 1.2 that ad revenue is greater with targeting if $\sigma > \frac{1}{3}$. However, if $\sigma \leq \frac{1}{3}$, that is not necessarily the case. The smaller the σ, the lower the ad price the platforms can charge to make an impression on non-exclusive consumers. This is particularly harmful in combination with weak platform preferences (low t), since targeting then creates a greater shift from exclusive consumers to non-exclusive consumers. A larger proportion of less valuable non-exclusive consumers could, in this case, offset the advantages of an increased ad price.

Combining Lemma 1.3 and Proposition 1.2, gives us the following corollary:

Corollary 1.1 *Targeting can only be profitable in equilibrium if at least some consumers multi-home.*

1.4 Equilibrium analysis

1.4.1 The targeting decision

From Lemma 1.3 and Proposition 1.2, we know that targeting is a dominant strategy irrespective of the homing regime for $\sigma > 1/3$. If, however, $\sigma \leq 1/3$, platforms might prefer not to target (NT). When the platforms do not target, the consumers prefer to single-home, in which case it follows from Lemma 1.3 that targeting is the dominant strategy. Hence, we propose:

Proposition 1.3 *(The targeting decision) Suppose $\sigma \leq 1/3$. Platforms that do not target (NT) cannot be part of the equilibrium.*

Proof. See Appendix. ■

From Proposition 1.3, we can conclude that a potential Nash equilibrium must be one in which the platforms target. We therefore investigate the targeting equilibrium outcomes, searching for the Nash equilibrium.

1.4.2 Comparison of targeting equilibrium outcomes

We now proceed to comparing the market outcomes with pure single-homing and partial multi-homing, and examining the existence of Nash equilibria. In this part of the analysis, we restrict our attention to parameter values that fulfill the conditions for both the single-homing and the multi-homing model. From Condition 1.1, we have that this requires that $v > \frac{11}{4}\alpha$. To illustrate the key point, we make the following assumption:

Assumption 1.1 $v = 3\alpha$.

Assumption 1.1 is close to the minimum $v-$value. In the Robustness section in the Appendix, we show that the results we arrive at are also valid for $v > 3\alpha$, at least if non-exclusive consumers are not virtually worthless to advertisers.

Given Assumption 1.1, the condition that ensures partial multi-homing in the multi-homing regime (cf. conditions A.1 and A.2 in the Appendix A.1), non-negative prices, and full market coverage in the single-homing regime (cf. the lower bound of Condition 1.1), in addition to satisfying second-order and stability conditions, is given by the following assumption:

Assumption 1.2 *(Equilibrium)* $\max\{\frac{5}{2}\alpha,\ \frac{3}{2}\alpha\,(\sigma + 1)\} < t < \frac{10}{3}\alpha.$

The following proposition sums up the comparison of the targeting equilibrium outcomes:

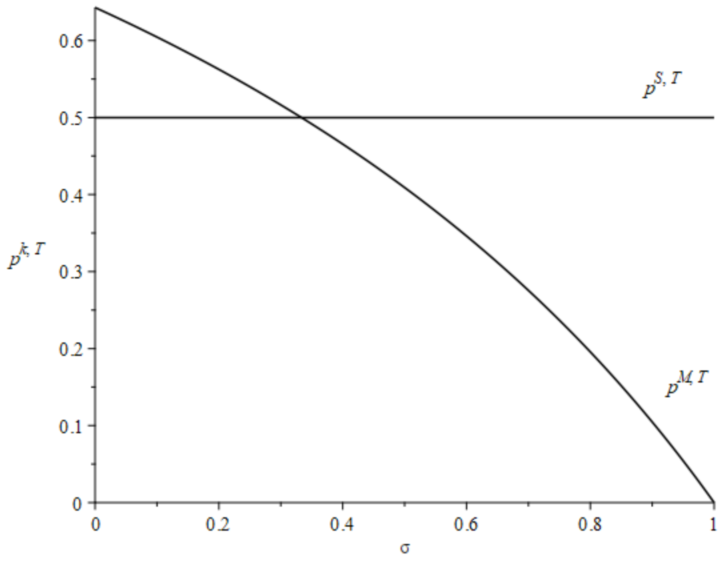

Figure 1.2: Equilibrium prices.

Proposition 1.4 *Assume that Assumption 1.2 holds and that $\sigma > \frac{2}{3}$. Compared to pure single-homing, multi-homing provides*

(i) lower subscription prices and higher consumer utility

(ii) higher ad revenue

(iii) higher platform profits

Proof. See Appendix. ∎

Comparing the subscription prices in Equation (1.15), we find that $p^{S,T} \geq p^{M,T}$ for $\sigma > \frac{2}{3}$. For lower σ, the single-homing price may be both greater and smaller than the multi-homing price, as illustrated in Figure 1.2 (parameter values: $t = 3\alpha$ and $\alpha = \frac{1}{2}$).

When σ is low, the platforms have weaker incentives to reduce the multi-homing price. However, the higher the t, the greater the price reduction required to persuade consumers to multi-home. Hence, if t is sufficiently high (see Condition A.3 given in the Appendix), the multi-homing price could still be lower than the single-homing price. Conversely, a higher σ (corresponding to non-exclusive consumers being more valuable) provides stronger incentives to reduce subscription prices in the multi-homing regime. This is why we observe that $p^{M,T}$ decreases in σ, both in absolute value and relative to $p^{S,T}$.

Turning to advertising prices, we find that these are always lower with single-homing ($\alpha^{S,T} < \alpha^{M,T}$). Finally, we consider profits. We find that if $\sigma \geq 0.65$, single-homing profits cannot be greater than multi-homing profits ($\pi^{S,T} < \pi^{M,T}$). For $\sigma < 0.65$, however, profits may or may not be greater with single-homing. A sufficiently high t can ensure that single-homing makes the

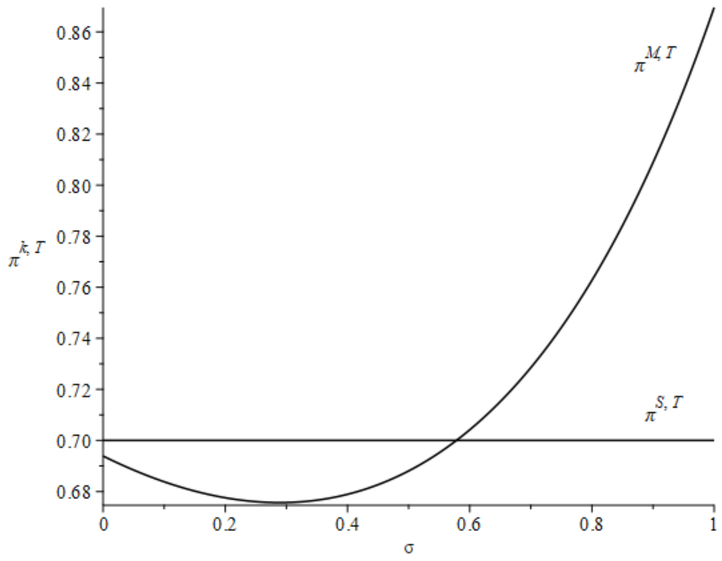

Figure 1.3: Equilibrium profits.

platforms better off. This is illustrated by Figure 1.3 (parameter values: $t = 3.3\alpha$ and $\alpha = \frac{1}{2}$).[17]

From the analysis of subscription prices, we know that consumers who only subscribe to one platform are better off in a multi-homing regime when $\sigma > \frac{2}{3}$, since $p^{S,T} \geq p^{M,T}$.

Moreover, we find that at least some consumers prefer multi-homing over single-homing if $\sigma > \frac{2}{9}$.

By nature, single-homing profits do not depend on the value of non-exclusive consumers (σ). Multi-homing profits, on the other hand, are either increasing in σ or have a U-shaped relationship with σ. An increase in σ means that non-exclusive consumers are more valuable to advertisers. Since this allows the platforms to charge a higher ad price, it could be also expected to lead to greater platform profits. For most parameter values, profits are indeed unambiguously increasing in σ. An increase in the value of non-exclusive consumers also makes the platforms eager to attract more of them. However, if we suppose that consumers have very strong platform preferences (high t), attracting a larger audience may require a price drop that is more costly than the additional revenue from gained consumers. This could be the case if the value of non-exclusive consumers—even after an increase—remains fairly low. Consequently, the overall impact on profits could be negative. However, as σ takes on higher values, profits will eventually start to increase. Figure 1.3 illustrates this U-shaped relationship between σ and multi-homing profits.

[17] We use different sets of parameter values in the two figures as this enables us to demonstrate that prices and profits can be both higher and lower with single-homing compared to multi-homing.

1.4.3 The existence of subgame-perfect Nash equilibria

Finally, we investigate whether single-homing and multi-homing constitute potential subgame-perfect Nash equilibria.

We propose the following:

Proposition 1.5 *Assume that Assumption 1.2 holds. There will then exist*

(i) a unique subgame-perfect Nash equilibrium in which platforms target and consumers multi-home for all $\sigma > 1/3$

(ii) no equilibrium with single-homing for all $\sigma > 0$.

Proof. See Appendix. ■

Proposition 1.5 consists of two results. First, note that it follows from Proposition 1.3 that only targeting can be a Nash equilibrium, and further that a targeting equilibrium is only stable for $\sigma > 1/3$. From Corollary 1.1, we have that targeting can only be profitable in equilibrium if at least some consumers multi-home. In order for the Nash equilibrium in which platforms target and consumers multi-home to be subgame perfect, no player can have incentives to deviate from targeting and multi-homing.

If non-exclusive consumers are sufficiently valuable (σ is sufficiently large), it pays off to charge lower subscription fees and forgo some subscription revenue in order to extract more ad-side revenue. If, on the other hand, the advertiser valuation of non-exclusive consumers is low (small σ), multi-homing might not constitute an equilibrium. In a situation with weak platform preferences (low t), a reduction in the subscription price would be efficient in attracting many consumers, making it tempting to undercut the rival's subscription price and only serve more valuable exclusive consumers. Both platforms would in such case deviate from multi-homing. However, we find that it is never beneficial for a platform to deviate from multi-homing as long as $\sigma > 0.03$, and a targeting equilibrium in which consumers multi-home (which is stable for $\sigma > 1/3$) is therefore subgame perfect.

The second result concerns single-homing. Unless non-exclusive consumers have very little value for advertisers, the platforms have strong incentives to deviate from setting the single-homing price. More precisely, we find that it is profitable for a platform to deviate from single-homing for all $\sigma > 0.1$. Yet even if non-exclusive consumers are not that valuable (i.e., $\sigma < 0.1$), single-homing does not constitute an equilibrium. The multi-homing prices would still be so low that some single-homing consumers would want to deviate and subscribe to both platforms.

The second result of Proposition 1.5 is particularly interesting. Previous literature has typically made the stark assumption of single-homing, which, we find, never takes part in a subgame-perfect Nash equilibrium when platforms can acquire targeting technologies. This may hence not be an appropriate assumption to make.

1.5 Concluding remarks

This paper makes two major contributions. First, we demonstrate the importance of targeting using first-party data for the strategic interaction between competing digital platforms. Whereas previous works on platform competition that do not consider targeting have established a strategic-independence result when consumers multi-home, we find that by implementing targeting, the strategic dependence is restored. This is because the value in the ad market of a platform's consumer mass can be affected by a rival platform's price setting, such that the composition of the demand becomes important. Hence, we find that targeting does not trigger an aggressive price response from the rival platform as would be the case in a single-homing regime. An important implication as such is our finding that targeting can indeed be profitable, contrary to the predictions of most media models, but only if non-exclusive consumers are sufficiently valuable in the ad market.

The second key contribution is an even more important one: we find that pure single-homing never occurs in equilibrium. This means that existing literature that assumes single-homing might be misleading when analyzed in a digital context where platforms target ads, and emphasizes that assessing the nature of consumer purchasing behavior (i.e., single-homing or multi-homing) is vital to fully understand the impact of targeting.

Our model makes the simplifying assumption of ad-neutral consumers. Targeting could, however, either increase or reduce ad nuisance. On the one hand, privacy concerns might lead to lower consumer satisfaction (Johnson, 2013; Kox et al., 2017), while on the other, more relevant ads could please them (Gong et al., 2019). The overall effect is therefore ambiguous. We leave this analysis for future research, however. Our model specification conveys that the platforms' targeting ability increases at a constant rate as more consumers subscribe. While some sources claim that more data means better targeting, others suggest that the benefit of more data will at some point diminish. We have not formally analyzed this issue, but we do not believe that it would change the key properties. Targeting would presumably still provide similar, but perhaps somewhat smaller effects.

One may also ask whether stricter privacy regulations provide greater incentives to cooperate in order to share data. On the one hand, joining forces to increase the total data pool could be seen as an alternative to purchasing third-party data, or facilitating entry into data-intensive markets.

On the other hand, stricter regulations might make cooperation less feasible. Furthermore, the perhaps greatest advantage of first-party data is that it provides the platforms with exclusive insight. This advantage clearly speaks against sharing. Future studies could explore this issue further.

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Appendix A

A.1 Conditions for multi-homing

Without targeting, second-order and stability conditions are always satisfied. From the equilibrium price, which is given by $p^{M,NT} = \frac{v-\sigma\alpha}{2}$, we see that $v > \sigma\alpha$ is required for the price to be positive. The non-targeting equilibrium demand functions are given by

$$x^{e,M,NT} = \frac{2t - v - \alpha\sigma}{2t} \; ; \; x^{n,M,NT} = \frac{v + \alpha\sigma - t}{t} \text{ and } D^{M,NT} = \frac{v + \alpha\sigma}{2t}.$$

The restriction of the analysis to partial multi-homing implies that we need $x^{e,M} > 0$ and $x^{n,M} > 0$. This places some additional constraints on the parameter values: $\frac{1}{2}(v + \sigma\alpha) < t < v + \sigma\alpha$.

With targeting, stability requires $t > \frac{1}{2}\alpha(1 + \sigma)$ and the second-order condition is satisfied for $t > \sigma\alpha$. The equilibrium price is given by Equation (1.15), and non-negative prices require that $t > \frac{\alpha v(3\sigma-1)}{v-\alpha}$. The targeting equilibrium demand functions are

$$x^{e,M,T} = \frac{2t - v - 3\alpha\sigma}{2t + \alpha(1 - 3\sigma)} \; ; \; x^{n,M,T} = \frac{2(v - t) + \alpha(1 + 3\sigma)}{2t + \alpha(1 - 3\sigma)} \text{ and } D^{M,T} = \frac{\alpha + v}{2t + \alpha(1 - 3\sigma)},$$

for which partial multi-homing is ensured by $\frac{1}{2}(v + 3\alpha\sigma) < t < v + \frac{1}{2}\alpha(1 + 3\sigma)$.

In summary, this leaves us with the two binding constraints, depending on the value of σ:

Condition A.1 *(Multi-homing)* $\max\{\frac{1}{2}(v+3\sigma\alpha), \frac{\alpha v(3\sigma-1)}{v-\alpha}\} < t < v+\sigma\alpha$ *for* $\sigma > \frac{1}{3}$.

Condition A.2 *(Multi-homing)* $\max\{\frac{1}{2}(v+3\sigma\alpha), \frac{1}{2}\alpha(1+\sigma)\} < t < v+\sigma\alpha$ *for* $\sigma \leq \frac{1}{3}$.

Finally, Condition A.1 constrains $v > \alpha\left(\sigma + \sqrt{\sigma(\sigma+1)}\right)$.

A.2 Omitted proofs

Proof of Lemma 1.2

Under single-homing, Lemma 1.2 follows directly as $p^{S,T} - p^{S,NT} = t - 2\alpha - (t-\alpha) = -\alpha < 0$. Under multi-homing, we have $p^{M,T} - p^{M,NT} = -\frac{\alpha}{2(2t+\alpha(1-3\sigma))}(2t(1+\sigma) - (v+\sigma\alpha)(1-3\sigma))$, which is negative if conditions A.1 and A.2 hold. ■

Proof of Lemma 1.3

Consider the single-homing regime. Suppose platform i targets ads, while platform j does not. The best-response functions are then

$$p_i(p_j) = \frac{t(t-2\alpha) + p_j(t-\alpha)}{2t-\alpha} \text{ and } p_j(p_i) = \frac{t+p_i-\alpha}{2}.$$

The equilibrium prices are given by (superscript 'd' for deviation)

$$p_i^d = \frac{3t(t-2\alpha)+\alpha^2}{3t-\alpha} \text{ and } p_j = \frac{3t^2 - 5\alpha t + \alpha^2}{3t-\alpha},$$

yielding profits

$$\pi_i^d = \frac{9t^2(2t-\alpha)}{4(3t-\alpha)^2} \text{ and } \pi_j = \frac{t(3t-2\alpha)^2}{2(3t-\alpha)^2}.$$

Equation (1.17) gives the symmetric equilibrium profits when both platforms target and when neither of the platforms target.

The decision of whether or not to deviate can be formulated as a game matrix, as shown in Table A.1.

		Platform i Target	**Platform i** Not target
Platform j	Target	$\frac{t}{2} - \frac{\alpha}{4}, \frac{t}{2} - \frac{\alpha}{4}$	$\frac{9t^2(2t-\alpha)}{4(3t-\alpha)^2}, \frac{t(3t-2\alpha)^2}{2(3t-\alpha)^2}$
	Not target	$\frac{t(3t-2\alpha)^2}{2(3t-\alpha)^2}, \frac{9t^2(2t-\alpha)}{4(3t-\alpha)^2}$	$\frac{t}{2}, \frac{t}{2}$

Table A.1: Prisoner's dilemma.

If platform j targets, it is optimal for platform i to target iff $\left(\frac{t}{2}-\frac{\alpha}{4}\right)-\frac{t(3t-2\alpha)^2}{2(3t-\alpha)^2}=\frac{\alpha(3t^2-\alpha^2)}{4(3t-\alpha)^2}>0$, which is always the case.

If platform j does not target, it is nonetheless optimal for platform i to target iff $\frac{9t^2(2t-\alpha)}{4(3t-\alpha)^2}-\frac{t}{2}=\frac{t\alpha(3t-2\alpha)}{4(3t-\alpha)^2}>0$, which is also always the case.

Hence, platform i's dominant strategy is to target, regardless of the rival's decision. Since $\pi_i^{S,T}-\pi_i^{S,NT}=\left(\frac{t}{2}-\frac{\alpha}{4}\right)-\frac{t}{2}=-\frac{\alpha}{4}<0$, the dominant strategy (targeting) yields lower profits than not targeting. This means that the platforms end up in a prisoner's dilemma when consumers single-home. ■

Proof of Proposition 1.2

To prove Proposition 1.2, we start by decomposing profits into ad revenue and subscription revenue.

Subscription revenues First, we show that equilibrium subscription revenue is always lower with targeting.

Lemma A.1 $p^{M,T}D^{M,T}-p^{M,NT}D^{M,NT}<0$ *for all* $\sigma\in[0,1]$.

Proof. Inserting the multi-homing prices from Equations (1.14) and (1.15) into multi-homing demand in (1.5), we find that $p^{M,T}D^{M,T}-p^{M,NT}D^{M,NT}=-\alpha^2\frac{\mathfrak{A}\times\mathfrak{B}}{4t(2t+\alpha(1-3\sigma))^2}$, where $\mathfrak{A}=2t(1-\sigma)-(v+\alpha\sigma)(1-3\sigma)$ and $\mathfrak{B}=2t(1+\sigma)+(v-\alpha\sigma)(1-3\sigma)$. It follows that

$$\begin{aligned}\mathfrak{A}>0 &\text{ if } 2t(1-\sigma)>(v+\alpha\sigma)(1-3\sigma)\\ &\implies t>\frac{(v+\alpha\sigma)(1-3\sigma)}{2(1-\sigma)}\end{aligned}\tag{A.1}$$

and

$$\begin{aligned}\mathfrak{B}>0 &\text{ if } 2t(1+\sigma)>(v-\alpha\sigma)(1-3\sigma)\\ &\implies t>\frac{(v-\alpha\sigma)(1-3\sigma)}{2(1+\sigma)}.\end{aligned}\tag{A.2}$$

First, if $\sigma>1/3$, then the conditions in Equations (A.1) and (A.2) are less strict than the upper bound of Condition A.1, such that $\mathfrak{A},\mathfrak{B}<0$, and therefore $p^{M,T}D^{M,T}-p^{M,NT}D^{M,NT}<0$ for $\sigma>1/3$.

Second, if $\sigma<1/3$, the conditions in Equations (A.1) and (A.2) are binding under Condition A.2, such that $\mathfrak{A},\mathfrak{B}>0$, and therefore $p^{M,T}D^{M,T}-p^{M,NT}D^{M,NT}<0$ for $\sigma<1/3$.

Hence, $p^{M,T}D^{M,T}-p^{M,NT}D^{M,NT}<0$ for all $\sigma\in[0,1]$. ■

Ad revenue We now investigate how targeting impacts advertising revenue.

Lemma A.2 $A^{M,T} - A^{M,NT} > 0$ *for all* $\sigma > 1/3$.

Proof. Inserting the multi-homing prices from Equations (1.14) and (1.15) into multi-homing demands in (1.3), (1.4), and (1.5), and into the targeting function in (1.11) and ad revenue in (1.7), we find that equilibrium advertising revenue with targeting minus ad revenue without targeting is given by

$$A^{M,T} - A^{M,NT} =$$
$$\alpha \frac{4t^2(1-\sigma)(v+2\alpha\sigma)+2tv^2(2\sigma-1)+2tv\alpha\sigma(9\sigma-5)+2t\alpha^2\left(5\sigma-13\sigma^2+12\sigma^3-1\right)+\alpha^2(1-2\sigma)(1-3\sigma)^2(v+\alpha\sigma)}{2t(2t+\alpha-3\alpha\sigma)^2}.$$

We find it useful to consider $\sigma > \frac{1}{3}$ and $\sigma \leq \frac{1}{3}$ separately.

For $\sigma > \frac{1}{3}$, we have that the minimum $v-$value, $v_{\min} = \alpha + \varepsilon$, where $\varepsilon \to 0$, ensures higher profits with targeting:

$$A^{M,T} - A^{M,NT}|_{v=\alpha} = \alpha \frac{\left(4t^2(1-\sigma)\alpha(2\sigma+1)+4t\alpha^2\left(\sigma-2\sigma^2+6\sigma^3-1\right)+\alpha^3(\sigma+1)(1-2\sigma)(1-3\sigma)^2\right)}{2t(2t+\alpha(1-3\sigma))^2},$$

which is positive under Condition A.1.

Moreover, the difference between profits with and without targeting becomes greater as v increases:

$$\frac{d(A^{M,T}-A^{M,NT})}{dv} =$$
$$\frac{\alpha}{2t(2t+\alpha(1-3\sigma))^2}\left(4t^2(1-\sigma) + 2t\alpha\sigma(9\sigma-5) + 4tv(2\sigma-1) + \alpha^2(1-2\sigma)(1-3\sigma)^2\right) > 0.$$

Hence, $A^{M,T} > A^{M,NT}$ for all $\sigma > \frac{1}{3}$. ■

We then consider $\sigma \leq \frac{1}{3}$. If t is low, a reduction in the subscription price will turn many exclusive consumers into non-exclusive consumers. However, if the non-exclusive consumers are not worth much in the ad market, the benefit for the platform is limited. This implies that even though targeting increases the ad price, it does not necessarily increase ad revenue when $\sigma \leq \frac{1}{3}$. We illustrate with an example:

Suppose that $\sigma = 0$, which yields

$$A^{M,T} - A^{M,NT} = \alpha \frac{(2t-v)\left(2tv-\alpha^2\right)}{2t\,(2t+\alpha)^2}.$$

The expression is positive if $2tv > \alpha^2$. If t and v are not sufficiently high relative to α, this is not the case. Consider, for instance, $v = 0.3$, $t = 0.3$ and $\alpha = \frac{1}{2}$. The numerator $(2t-v)\left(2tv-\alpha^2\right)$ then equals -0.021, which implies that $A^{M,T} - A^{M,NT} < 0$.

Platform profits We then go on to analyze the platform profits. From Lemma A.1, we know that subscription revenue is lower with targeting. From Lemma A.2, we know that ad revenue is higher with targeting if $\sigma > 1/3$. We now investigate whether higher ad revenue compensates for lower subscription revenue.

By inserting Equations (1.15) and (1.14) into (1.8), we find the equilibrium profits with and without targeting, respectively, when consumers multi-home:

$$\pi^{M,T} = \frac{(t-\alpha\sigma)(\alpha+v)^2}{(2t+\alpha(1-3\sigma))^2} + \frac{\alpha(2t-v)}{(2t+\alpha(1-3\sigma))} - \alpha\sigma\left(1+\frac{2\alpha-v}{2t+\alpha(1-3\sigma)}\right) \tag{A.3}$$

and

$$\pi^{M,NT} = \frac{1}{4t}(v^2+2v\alpha(2\sigma-1)+3\alpha^2\sigma^2-2\alpha^2\sigma-4t\alpha(1-\sigma)). \tag{A.4}$$

Whether higher ad revenue compensates for lower subscription revenue is dependent on σ. We start by considering $\sigma > \frac{1}{3}$. The minimum $v-$value is given by $v_{\min} = \alpha + \varepsilon$. By definition, $\sigma_{\min} = \frac{1}{3} + \varepsilon$. Evaluating the multi-homing profits of Equation (A.3) and (A.4) at $v_{\min}$ and $\sigma_{\min}$, we see that targeting in both cases provides greater profits ($\pi^{M,T} > \pi^{M,NT}$):

$$\pi^{M,T} - \pi^{M,NT}|_{v_{min}} = \alpha^2\frac{(2t-\alpha)^2+9\alpha\sigma^3(4t-3\alpha\sigma)+6\sigma^2\left(-2\alpha t+3\alpha^2-2t^2\right)-4\sigma\left(\alpha t+2\alpha^2-2t^2\right)}{4t(2t+\alpha(1-3\sigma))^2} > 0$$

and

$$\pi^{M,T} - \pi^{M,NT}|_{\sigma_{min}} = \frac{\alpha}{12t^2}\left(4tv-(v+\alpha)^2\right) > 0.$$

Moreover, for $v_{\min}$, we have that $(\pi^{M,T} - \pi^{M,NT})$ is increasing in σ :

$$\frac{d(\pi^{M,T}-\pi^{M,NT})}{d\sigma}|_{v_{min}} = \frac{\alpha^2(\alpha^3(3\sigma+1)(3\sigma-1)^3-8t^3(3\sigma-1)-2\alpha^2t\left(-9\sigma-27\sigma^2+81\sigma^3+11\right)+12\alpha t^2\left(-2\sigma+9\sigma^2+1\right)}{2t(2t+\alpha(1-3\sigma))^3} > 0.$$

Similarly, $(\pi^{M,T} - \pi^{M,NT})$ is increasing in v for $\sigma_{\min}$:

$$\frac{d(\pi^{M,T}-\pi^{M,NT})}{dv}|_{\sigma_{min}} = \frac{\alpha(2t-v-\alpha)}{6t^2} > 0.$$

Finally, higher $v-$values enhance the increase in $(\pi^{M,T} - \pi^{M,NT})$ in response to a change in σ :

$$\frac{d\left(\frac{d(\pi^{M,T}-\pi^{M,NT})}{d\sigma}\right)}{dv} = \alpha\frac{2\alpha^3(3\sigma-1)^3+12\alpha t^2(5\sigma-1)-4\alpha^2t\left(5-18\sigma+27\sigma^2\right)+4tv(4t-\alpha(1-3\sigma))-8t^3}{2t(2t+\alpha(1-3\sigma))^3} > 0.$$

The numerator is increasing in v, and since it is positive for $v_{\min}$, it is also positive for larger $v-$values. In sum, targeting is profitable in equilibrium if $\sigma > \frac{1}{3}$.

Consider, further, the case where $\sigma \leq \frac{1}{3}$. In this case, targeting does not necessarily increase ad revenue. Since targeting also reduces subscription revenue, it might lead to lower profits.

To complete the proof, we consider mixed strategies and whether any unilateral deviation from targeting is profitable. Suppose platform i targets ads, while platform j does not. The best-response (BR) functions are then

$$p_i^{BR}(p_j) = \frac{v\,(t+\alpha) - \alpha\,(t + 3v\sigma) - \alpha p_j\,(1-\sigma)}{2(t-\alpha\sigma)} \tag{A.5}$$

and

$$p_j^{BR}(p_i) = \frac{v - \alpha\sigma}{2}. \tag{A.6}$$

Equation (A.5) is equivalent to Equation (1.13), whereas Equation (A.6) is equivalent to Equation (1.10). The best-response functions in Equation (1.10) are strategically independent, such that $p_j = p_j^{BR}(p_i) = p_j^{M,NT}$.

From Lemma 1.2, we know that the equilibrium prices $p_i^{M,T} < p_i^{M,NT}$, and since $\frac{\partial p_i^{M,T}(p_j)}{\partial p_j} < 0$, it must follow that $p_i^d < p_i^{M,T} < p_j = p_j^{M,NT}$, where p_i^d is the deviation price firm i obtains by targeting when the rival does not. It also follows that $\pi_i^d > \pi_j = \pi_j^{M,NT}$. The previous part of this proof confirmed that $\pi_i^{M,T} > \pi_i^{M,NT}$ for $\sigma > 1/3$. Hence, targeting is a dominant strategy for platform i if non-exclusive consumers are worth a sufficiently large value to the platform in the ad market, i.e., for $\sigma > 1/3$, which concludes the proof. ■

Proof of Proposition 1.3

Comparing the non-targeting profits under the two homing regimes (Equations (1.17) and (A.4)), we find that

$$\pi^{S,NT} > \pi^{M,NT} \tag{A.7}$$

could be true for $\sigma \leq 1/3$ (and $v < \sqrt{2t^2 + 4\alpha(1-\sigma)t + (\alpha^2(\sigma^2 - 2\sigma + 1))} + \alpha(1-2\sigma)$, i.e., v is sufficiently small). As such, the platform would prefer to set prices that incentivize consumers to single-home.

Next, we therefore investigate whether the consumers will single-home. We first investigate the deviation incentives to and from single-homing behavior.

1. **Deviation from single-homing:** Facing single-homing prices, could consumers be better off by multi-homing? Single-homing prices are given by Equation (1.14), $p^{S,NT} = t - \alpha$.

Inserting the single-homing price in the absence of targeting into the consumer utility functions, we find that $u_{ij}^{p=p^{S,NT}} - u_{i}^{p=p^{S,NT}} < 0$ for $t < \frac{2}{3}(v+\alpha)$ (cf. Condition 1.1). Hence, consumers will not deviate from single-homing prices.

2. **Deviation from multi-homing:** Facing multi-homing prices, could consumers be better off by single-homing? The multi-homing prices are given by Equation (1.14). Inserting the multi-homing price in the absence of targeting into the consumer utility functions, we find that $u_{ij}^{p=p^{M,NT}} - u_{i}^{p=p^{M,NT}} < 0$ for $t < \alpha\sigma + v$ (cf. Condition A.2). Hence, if the consumer faces multi-homing prices, they will deviate and only subscribe to one platform (i.e., single-home).

That is, if $\sigma \leq 1/3$ and the platform chooses to not use targeting technologies, then both the platform and the consumer would deviate to single-homing prices. According to Lemma 1.3, the platform would then deviate and implement a targeting technology after all. Hence, platforms' no-targeting (NT) strategy cannot be part of an equilibrium. ■

Proof of Proposition 1.4

The proof consists of three parts:

(i) a) **Subscription prices:** The subscription prices are given in Equation (1.15). The single-homing prices are larger than the multi-homing prices, $p^{S,T} - p^{M,T} = \frac{2t^2-5\alpha^2(1-3\sigma)-\alpha t(5+3\sigma)}{2t+\alpha(1-3\sigma)} > 0$, for $\sigma > \frac{2}{3}$ under Assumption 1.2. For lower values of $\sigma \in [0, \frac{2}{3}]$, $p^{S,T} - p^{M,T} > 0$ requires the following stricter lower-bound constraint:

Condition A.3 $\frac{1}{4}\left(\sqrt{\alpha^2(9\sigma^2-90\sigma+65)} + 3\alpha\sigma + 5\alpha\right) < t < \frac{10\alpha}{3}$.

Otherwise, i.e., for $\max\{\frac{5}{2}\alpha,\ \frac{3}{2}\alpha\,(\sigma+1)\} < t < \frac{1}{4}\left(\sqrt{\alpha^2(9\sigma^2-90\sigma+65)} + 3\alpha\sigma + 5\alpha\right)$, the single-homing price might be lower.

b) **Consumer utility:** To show that consumer utility is higher with multi-homing, we need to compare the utility from subscribing to one platform with that of subscribing to two platforms. The utility from subscribing to only one platform is $u_{i}^{p=p^{S,T}}(x=1/2) = 5\alpha - \frac{3}{2}t$, whereas the utility from subscribing to both platforms is given by $u_{ij}^{p=p^{M,T}}(x=1/2) = t\frac{7\alpha-2t+3\alpha\sigma}{2t+\alpha(1-3\sigma)}$. Multi-homing is preferred if

$$u_{ij}^{p=p^{M,T}} - u_{i}^{p=p^{S,T}} = \frac{10\alpha^2(3\sigma-1) - 3\alpha t(1+\sigma) + 2t^2}{2(2t+\alpha(1-3\sigma))} > 0,$$

which holds for $\sigma > \frac{2}{9}$ under Assumption 1.2. From the analysis of subscription prices, we know that consumers who subscribe to only one platform are also better off when $\sigma > \frac{2}{3}$. Hence, a sufficient condition for all consumers to be better off with multi-homing is that $\sigma > \frac{2}{3}$.

(ii) **Ad prices:** The ad prices are given by

$$\alpha^{M,T} = \alpha \frac{2t + \alpha(5 - 3\sigma)}{2t + \alpha(1 - 3\sigma)} \text{ and } \alpha^{S,T} = \frac{3}{2}\alpha.$$

The difference in ad prices $\alpha^{S,T} - \alpha^{M,T} = -\frac{\alpha(7\alpha - 2t + 3\alpha\sigma)}{2(2t+\alpha(1-3\sigma))} < 0$, entails that the ad price is always higher with multi-homing.

(iii) **Profits:** The platform profits are given by Equations (A.3) and (1.17). The difference is given by

$$\pi^{S,T} - \pi^{M,T} = \frac{\left(36\alpha^3\sigma^3 - 3\alpha^2\sigma^2(7\alpha + 10t) + 2\alpha\sigma\left(16\alpha t + 17\alpha^2 - 4t^2\right) + 4t^2(2t - 3\alpha) - \alpha^2(50t - 11\alpha)\right)}{4(2t + \alpha(1 - 3\sigma))^2}.$$

We find that single-homing profits cannot be greater than multi-homing profits if $\sigma \geq 0.65$ when Assumption 1.2 holds. ■

Proof of Proposition 1.5

It follows from Proposition 1.3 that the targeting equilibrium is only stable for $\sigma > 1/3$. A stable equilibrium is one in which no player will deviate from a given strategy. The proof consists of two parts: We first examine the incentives to deviate from a multi-homing price setting, and then the incentives to deviate from a pure single-homing outcome. Finally, we find that consumers facing single-homing prices will always deviate and subscribe to an additional platform, such that single-homing can never be part of an equilibrium.

(i) Deviation from multi-homing

Suppose that platform i believes that the rival sets its prices according to the multi-homing regime: $p_j = \frac{v(t+\alpha) - \alpha(t+3v\sigma)}{2t+\alpha(1-3\sigma)}$. Could it then be optimal for platform i to charge a higher price and only sell to consumers who do not subscribe to platform j?

We insert $p_j = \frac{v(t+\alpha) - \alpha(t+3v\sigma)}{2t+\alpha(1-3\sigma)}$ into the location of the indifferent consumer:

$$\widetilde{x} = \frac{1}{2} + \frac{p_j - p_i}{2t},$$

which yields total demand

$$D_i = \frac{2t^2 + 3\alpha t + 3\alpha^2 - 3\alpha\sigma\,(3\alpha + t) - p_i\,(2t + \alpha(1 - 3\sigma))}{2t\,(2t + \alpha(1 - 3\sigma))}$$

and subscription price (superscript 'd' for deviation):

$$p_i^d = \frac{(2t-3\alpha)\left(\alpha t+\alpha^2+t^2\right)-3\alpha\sigma\left(t^2+\alpha t-3\alpha^2\right)}{(2t-\alpha)\left(2t+\alpha(1-3\sigma)\right)}.$$

Compared to the equilibrium price with multi-homing (Equation (1.15)), the deviation price is always higher if $\sigma > \frac{2}{3}$ (under Assumption 1.2). For lower values of $\sigma \in [0, \frac{2}{3}]$, $p_i^d - p_i^{M,T} > 0$ holds under Condition A.3. The deviation profit is given by

$$\pi_i^d = \frac{\left(2t^2+\alpha t(5-3\sigma)+4\alpha^2(1-3\sigma)\right)^2}{4\left(2t-\alpha\right)\left(2t+\alpha(1-3\sigma)\right)^2}.$$

Comparing deviation profits with the multi-homing equilibrium profit, we find that

$$\pi_i^d - \pi^{M,T} = \frac{4t^4+4\alpha t^3(5\sigma-3)-3\alpha^2t^2\left(10\sigma+29\sigma^2+13\right)+8\alpha^3t(3\sigma+7)\left(2-3\sigma+3\sigma^2\right)-4\alpha^4(\sigma-1)\left(1-30\sigma+9\sigma^2\right)}{4(2t-\alpha)(2t+\alpha(1-3\sigma))^2}.$$

It can be shown that deviation is never profitable, i.e., $\pi_i^d - \pi^{M,T} < 0$ for all $\sigma > 0.03$.

However, for multi-homing to be an equilibrium, it must be true that consumers will actually purchase both products when $p = p^{M,T}$.

From

$$u_i^{p=p^{M,T}}\left(x=\frac{1}{2}\right) = \frac{t}{2}\left(\frac{7\alpha-2t+3\alpha\sigma}{2t+\alpha(1-3\sigma)}\right)$$

and

$$u_{ij}^{p=p^{M,T}}\left(x=\frac{1}{2}\right) = t\left(\frac{7\alpha-2t+3\alpha\sigma}{2t+\alpha(1-3\sigma)}\right),$$

we see that $u_{ij}^{p=p^{M,T}} - u_i^{p=p^{M,T}} = \frac{t}{2}\left(\frac{7\alpha-2t+3\alpha\sigma}{2t+\alpha(1-3\sigma)}\right) > 0$ whenever Assumption 1.2 holds, which confirms that some consumers want to multi-home. Hence, (some) multi-homing consumers have no incentives to deviate (subscribe to only one platform) when facing multi-homing prices, and there is a unique equilibrium with multi-homing.

(ii) Deviation from single-homing

If both platforms price according to single-homing, prices and profits are given by $p^{S,T} = t - 2\alpha$ and $\pi^{S,T} = \frac{1}{4}\left(2t-\alpha\right)$. Suppose that platform i believes that platform j sets the single-homing price, $p^{S,T}$. If platform i deviates and sets the prices that maximize profits if also selling to some consumers who buy the rival's product, we get:

$$p_i^d = \frac{\alpha t\left(\sigma+1\right)-\alpha^2\left(11\sigma-5\right)}{2(t-\alpha\sigma)}.$$

Deviation profit is given by:

$$\pi_i^d = \alpha \frac{25\alpha^3 (1-\sigma)^2 + 8t^3 (1-\sigma) + \alpha t^2 \left(2\sigma + 9\sigma^2 + 5\right) - 10\alpha^2 t (1-\sigma)(5-3\sigma)}{4t^2 (t-\alpha\sigma)}$$

and

$$\pi_i^d - \pi^{S,T} = \frac{-2t^4 + 25\alpha^4 (1-\sigma)^2 - 10\alpha^3 t (1-\sigma)(5-3\sigma) + \alpha^2 t^2 \left(\sigma + 9\sigma^2 + 5\right) + 3\alpha t^3 (3-2\sigma)}{4t^2 (t-\alpha\sigma)}.$$

Examining the above equations shows that deviation is profitable when $\sigma > 0.1$. For $t-$values at the higher end of the condition in Assumption 1.2, it might also be the case for $\sigma < 0.1$.

Suppose next that for some $\sigma < 0.1$, it is optimal for the platforms to set the single-homing price. This can only be an equilibrium if the consumers do not subscribe to both platforms at this price. We insert $p^{S,T}$ into (1.1) and (1.2) for $x = \frac{1}{2}$ and find

$$u_i^{p=p^{S,T}}\left(x = \frac{1}{2}\right) = \frac{1}{2}\Big(10\alpha - 3t\Big)$$

and

$$u_{ij}^{p=p^{S,T}}\left(x = \frac{1}{2}\right) = 10\alpha - 3t.$$

We see that $u_{ij}^{p=p^{S,T}} > u_i^{p=p^{S,T}}$, which implies that there are consumers who want to subscribe to both platforms when $p = p^{S,T}$. By the same token, deviation is only possible if some consumers actually subscribe to both platforms at the deviation price. We insert $p^{S,T}$ and p_i^d into (1.1) and (1.2), respectively, and find

$$u_i^{p=p^{S,T}}\left(x = \frac{1}{2}\right) = \frac{1}{2}(10\alpha - 3t)$$

and

$$u_{ij}^{p=p_i^d}\left(x = \frac{1}{2}\right) = \frac{3\alpha t(\sigma+5) - 5\alpha^2(\sigma+1) - 4t^2}{2(t-\alpha\sigma)}.$$

At $x = \frac{1}{2}$, $u_{ij}^{p=p_i^d} > u_i^{p=p^{S,T}}$, and there will thus be consumers who want to multi-home. Some consumers have incentives to deviate and subscribe to more platforms when facing single-homing prices. Therefore, a single-homing Nash equilibrium cannot be subgame-perfect. ■

A.3 Robustness

In the equilibrium analysis, we assume that $v = 3\alpha$ (Assumption 1.1). This provides us with a more tractable set of constraints. We will now take a closer look at how the results depend on v.

First, note that $\pi^{S,T}$ does not depend on v, while $\partial\pi^{M,T}/\partial v > 0$ if

$$v > \mu \equiv \frac{\alpha^2\left(1-2\sigma+3\sigma^2\right)-2\alpha t\sigma}{2\left(t-\alpha\sigma\right)}. \tag{A.8}$$

Since $\partial\mu/\partial t < 0$, the requirement is strictest for $t_{\min}$. From the conditions (1.1), (A.1) and (A.2), we know that the lowest possible t is given by $\frac{5}{2}\alpha$. This gives $\mu|_{t=\frac{5\alpha}{2}} = \alpha\frac{3\sigma^2-7\sigma+1}{5-2\sigma}$, which is at its highest when $\sigma = 0$ and yields $\mu = \frac{1}{5}\alpha$. Hence, multi-homing becomes relatively more profitable compared to single-homing for all $v > \frac{1}{5}\alpha$.

We then consider how v affects the platforms' incentives to deviate from committing to single-homing and multi-homing. We thus propose the following:

Proposition A.1 *Deviation from single-homing is more tempting for a platform as v increases for all $\sigma \in [0.01, 1]$.*

Proof. If the rival commits to single-homing, the deviation profit is given by

$$\pi_i^{d,S} = \frac{t^2v(v+2\alpha\sigma)+\alpha^2(\sigma-1)^2(2\alpha+v)^2+8\alpha t^3(1-\sigma)-2\alpha tv(\sigma-1)(-4\alpha-v+3\alpha\sigma)+\alpha^2t^2\left(-4\sigma+9\sigma^2-4\right)-4\alpha^3t(3\sigma-2)(\sigma-1)}{4t^2(t-\alpha\sigma)}.$$

Consequently, $\frac{d(\pi_i^d-\pi^{S,T})}{dv} > 0$ if $v > \lambda \equiv \frac{\alpha^2t(\sigma-1)(3\sigma-4)-2\alpha^3(\sigma-1)^2-\alpha t^2\sigma}{(t-\alpha+\alpha\sigma)^2}$.

The upper bound of the multi-homing conditions A.1 and A.2 constrains $t < v+\sigma\alpha$. It follows that $v > t-\sigma\alpha > \lambda$ if $t-\sigma\alpha-\lambda > 0$. We have that:

$$t-\sigma\alpha-\lambda = \frac{t^3+\alpha^3\left(2-\sigma\right)\left(1-\sigma\right)^2+t\alpha^2\left(4\sigma-3\right)\left(1-\sigma\right)-2t^2\alpha\left(1-\sigma\right)}{\left(t-\alpha(1-\sigma)\right)^2}$$

is positive for all $\sigma > 0.01$. Hence, unless multi-homing consumers are almost worthless in the ad market, it is more tempting to deviate from single-homing as v increases from $v = 3\alpha$. ∎

Similarly, we consider deviation from multi-homing. We propose:

Proposition A.2 *Deviation from multi-homing is less tempting for a platform as v increases for all $\sigma \in [0.026, 1]$.*

Proof. If the rival commits to multi-homing, a platform will make the following profit by deviating to single-homing:

$$\pi_i^{d,M} = \frac{\left(2t\alpha+v\alpha+\alpha^2-3\alpha^2\sigma+tv+2t^2-3t\alpha\sigma-3v\alpha\sigma\right)^2}{4\left(2t-\alpha\right)\left(2t+\alpha(1-3\sigma)\right)^2}.$$

From the profit expression, we find that $\frac{d(\pi_i^d - \pi^{M,T})}{dv} < 0$ if

$$v > \mu \equiv \frac{2t^3 - \alpha^3\left(3\sigma+1\right)\left(1-\sigma\right) - t^2\alpha\left(17\sigma-4\right) + t\alpha^2\left(7-16\sigma+21\sigma^2\right)}{\left(t-\alpha(1-\sigma)\right)\left(7t+\alpha-9\alpha\sigma\right)}.$$

The upper bound of the multi-homing conditions A.1 and A.2 constrains $t < v+\sigma\alpha$. It follows that $v > t-\sigma\alpha > \mu$ if $t-\sigma\alpha-\mu > 0$. We then see that

$$t-\sigma\alpha-\mu = \frac{5t^3 + \alpha^3\left(1-\sigma\right)\left(4\sigma-9\sigma^2+1\right) - 4t\alpha^2(2-8\sigma+7\sigma^2) + 2t^2\alpha\left(4\sigma-5\right)}{\left(t-\alpha(1-\sigma)\right)\left(7t+\alpha-9\alpha\sigma\right)}$$

is positive for $\sigma > 0.026$. Hence, deviation from single-homing is less tempting as v increases from $v = 3\alpha$. ■

Suppose now that $\sigma = 0$. Since $\frac{d\mu}{d\sigma} < 0$, Equation (A.8) is at its highest when $\sigma = 0$:

$$\mu_{\max} = \frac{1}{\left(t-\alpha\right)\left(7t+\alpha\right)}\left(2t^3+4t^2\alpha+7t\alpha^2-\alpha^3\right). \tag{A.9}$$

For $t' \equiv t \leq 6.57\alpha$, we find that $v \geq 3\alpha \geq \mu_{max}$. From the condition $t < v+\sigma\alpha$, we have that $v > t'$ when evaluated at $\sigma = 0$ and $t = t'$. From Equation (A.9), we have $\frac{d\mu_{\max}}{dt'} > 0$. This implies that if $t' > \mu_{\max}$, then $v > \mu_{\max}$. Since

$$t' - \mu_{\max} = \frac{\alpha^3 - 8t\alpha^2 - 10t^2\alpha + 5t^3}{\left(t-\alpha\right)\left(7t+\alpha\right)} > 0.$$

Hence, deviation is less tempting for $v > 3\alpha$ also if $\sigma = 0$.

In this section, we have shown that our results are robust. Given that multi-homing consumers are not negligible in the ad market, our results hold for all $v > 3\alpha$. A higher v does not make single-homing more attractive relative to multi-homing and it does not reduce the incentives to deviate from single-homing. Moreover, a higher v makes it less imperative to deviate from multi-homing.

Consumers

For a general v, we check whether consumers actually will subscribe to both platforms when facing multi-homing prices, i.e., $p = p^{M,T}$. We propose the following:

Proposition A.3 *Consumers facing multi-homing prices, will not deviate.*

Proof. Inserting (1.15) into (1.1) and (1.2), we find the consumer's utility of single-homing

$$u_i^{p=p^{M,T}}\left(x=\frac{1}{2}\right) = \frac{t}{2}\left(\frac{2(v-t)+\alpha(1+3\sigma)}{2t+\alpha(1-3\sigma)}\right)$$

and multi-homing

$$u_{ij}^{p=p^{M,T}}\left(x=\frac{1}{2}\right)=t\left(\frac{2(v-t)+\alpha(1+3\sigma)}{2t+\alpha(1-3\sigma)}\right).$$

It follows that if $u_{ij}^{p=p^{M,T}} > u_{i}^{p=p^{M,T}}$ for $v=3\alpha$, the same is true for any other v-value as well. Hence, the consumers prefer to multi-home. ■

Chapter 2

Technology licensing and digital platform competition: cross-licensing under cross-side network effects

Chapter 2

Technology licensing and digital platform competition: cross-licensing under cross-side network effects

Atle Haugen*

NHH Norwegian School of Economics

Abstract

Digital platforms are technology intensive and often require access to intellectual property rights. As those rights are often owned by competing platforms, we observe cross-licensing contracts between them. Cross-licensing facilitates the sharing of technologies, leading to less duplication of resources and equal access to technology—facilitating competition on equal terms. Yet the economic literature has traditionally been worried for the anti-competitive effects of cross-licensing in the presence of monetary transfers in traditional (one-sided) markets, since a positive royalty essentially raises the rival's costs, leading to higher prices. Through a two-sided platform model, I show that positive royalties in cross-licensing contracts in two-sided markets have two opposing effects: the competition effect and the two-sided effect. The two-sided effect alleviates the anti-competitive effects, and may even flip the outcome. Under strong network effects, the two-sided effect of cross-licensing contracts may in fact dominate, leading to lower prices. The results suggest that policymakers should be less concerned about competition harm associated with cross-licensing contracts in markets with strong network effects.

Keywords: Technology licensing, intellectual property, network effects, digital platforms, two-sided markets.
JEL classification: D85, L13, L24, O34.

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2.1 Introduction

As digital industries are technology intensive, digital platforms often base their business models on technology protected by intellectual property rights, such as patents. According to the OECD (2014), ICT-related technologies account for about one-third of all applications to patent offices. Over the past decade, the number of granted patents across all industries in the US has more than doubled from about 180,000 in 2010 to 370,000 in 2020, and a similar development can be seen in the EU (USPTO, 2021; EPO, 2021). The digital platform industry has been an important driver for this patent surge.[1]

A cross-licensing contract is a contract between two or more firms that provides access to each others' intellectual properties, often in exchange for a royalty payment (see e.g., Shapiro, 2000).[2] The production of digital goods and services often relies on multiple technologies as inputs. In the case of digital platforms, the required patent rights are often owned by several companies in the industry, and even the most innovative companies require access to other companies' patents. To illustrate, one can think of each platform holding some form of standard-essential patent (SEP), the combination of which form a standard-essential technology (see e.g., Baron and Spulber (2018) for an overview of the organisation and scope of technology standards). Platforms can exchange patents through cross-licensing, and it is therefore a common practice. Google, for example, made broad cross-licensing agreements with the software developer SAP in 2015 (SAP News, 2015) and with the Chinese social media platform Tencent in 2018 (Lucas, 2018). Since 2017, Google has offered cross-licensing of Android to its competitors (Rosenberg, 2017). Although the specific content and terms of such cross-licensing contracts are often secret, we can observe substantial licensing payments across digital firms. In 2017, for example, Google paid Apple \$3 billion for licensing, which accounts for about 10 percent of Apple's non-advertising revenues, and one third of Google's traffic acquisition payments (Forbes, 2018). This paper analyses the competitive effects of cross-licensing contracts between digital platforms.

Cross-licensing has pro-competitive effects by facilitating the transfer of technology. Yet, as has been demonstrated in one-sided market analyses (see e.g., Katz and Shapiro, 1985; Fershtman and Kamien, 1992), cross-licensing can also have anti-competitive effects. Paying each other royalties leads to less price competition. Digital platforms, however, are characterised by being two-sided platforms, exhibiting strong cross-side network effects between their customer groups.

[1] In the US, computer technology and digital communication industries filed for roughly twice as many patents as the medical and pharmaceutical industry in 2019, and in Japan, AI-related industries grew by five times in the period 2010–2019 (WIPO, 2021; JPO, 2021).

[2] Cross-licensing resembles reciprocal access pricing, which was commonly used in telecommunications; see Armstrong, 1998, and Laffont, Rey and Tirole, 1998).

Notably, two-sided market analyses often show stark differences to one-sided markets, including crucial impact on pricing and firm profits. The main characteristic of platforms is to facilitate the interaction of different groups of customers on the platform by internalising the cross-group network effects. This, in turn, can also affect cross-licensing contracts. In this paper, I therefore investigate how cross-side network effects in two-sided markets affect competition concerns associated with cross-licensing.

To analyse the problem formally, I use the two-sided model of Armstrong (2006) as a workhorse model to analyse the importance of cross-licensing between two competing platforms. However, I add a new element to this workhorse model: The platform requires access to a technology owned by its competitor to produce the product or service offered to one side of the platform. At the same time, the platform provides the rival with access to its own technology, against a royalty fee. The platform must pay the rival a royalty based on its own sales value (i.e., ad valorem) on one side of the platform, and, likewise, the platform receives a royalty payment from the competitor based on the rival's sales to the same side of the platform.

This two-sidedness adds a new dimension to cross-licensing. In particular, prices might fall with the royalty. If the agents on one side of the platform benefit from the presence of agents on the other side (i.e., there are positive network effects), the platform will internalise those benefits and offer a lower price to customers on the other side. I find that the royalty gives an additional downward push on prices since the revenue from the side of the platform that pays a royalty becomes less important to the platform, while the other side becomes more important. To increase the other side's revenue, the platform therefore wants to attract more customers to the royalty-levied side. This is done by reducing the price to that side. If the network effects are sufficiently strong, the two-sided effect dominates, leading to lower prices to customers.

These results could have important policy implications. A policy maker should be less concerned about competition harm associated with cross-licensing contracts in markets with strong network effects.

Outline. The paper is organised as follows. In Section 2.2, I review the related literature, and in Section 2.3, I present the model set-up and discuss the benchmark with cross-licensing in one-sided markets. In Section 2.4, I analyse the impact of cross-licensing in two-sided markets, and solve for the equilibrium prices and profits, before solving for the optimal cross-licensing contract. Section 2.5 discusses the results and concludes.

2.2 Related literature

In this paper, I combine two strands of the literature; (i) that of cross-licensing, and (ii) that of two-sided markets and network effects.

Cross-licensing: The literature on cross-licensing highlights both its pro- and anti-competitive effects. First, licensing provides innovators with the prospect of earnings on their innovations, and thereby ensures a liquid market for innovation. Moreover, cross-licensing could be pro-competitive as it allows for efficient specialisations in production, such that each innovator innovates according to its comparative advantage (Grindley and Teece, 1997).

Second, the literature has also identified two sources of antitrust issues associated with cross-licensing. Katz and Shapiro (1985), Shapiro (1985) and Fershtman and Kamien (1992) all found that duopolists that engage in cross-licensing contracts have incentives to (endogenously) set high royalties, thereby raising the rival's costs and softening the competition. This result was also generalised by Jeon and Lefouili (2018) in a market whith more firms signing a multilateral cross-licensing contract. Laffont, Rey and Tirole (1998) found a similar result for a closely related topic, namely, the use of reciprocal access prices in telecommunication network industries. They argue that "freely negotiated access charges may prevent effective competition." Others have also pointed out how cross-licensing in itself can be a facilitating device for collusion (in the context of a repeated game; see, e.g., Eswaran, 1994).

Recently, attention has also been directed towards the use of royalty-free contracts. Whereas Régibeau and Rockett (2011) state that "royalty free patent exchange [...] does not raise antitrust issues with respect to unilateral effects", Choi and Gerlach (2019) argue that royalty-free contracts can be used as an entry-deterrence mechanism, since positive royalties would otherwise soften the incentives to litigate. The authors argue that "restraining the use of positive royalty cross-licensing rates to curb collusive outcomes may have adverse effects on entry of new competitors". In this paper, I do not consider probabilistic patents and entry. Instead, I demonstrate how royalty-free cross-licensing might be optimal to platforms due to strong cross-group network effects.

Two-sided markets: The literature on two-sided markets, emerging from the seminal contributions of, among others, Rochet and Tirole (2003; 2006), Caillaud and Jullien (2003) and Armstrong (2006), demonstrates how two-sided markets, by internalising the network externalities that each side exerts on the other, behave differently from one-sided markets. I contribute to this literature by studying the effects of two-sided markets in a different setting, namely, in the presence of cross-licensing, and show that cross-licensing provides different results under strong network effects. In this sense, the paper also relates to other topics, such as the tax literature analysing the impact of value-added taxes (VAT) in two-sided markets (Kind et al., 2008; Kind et al., 2013; Kind and Köthenbürger, 2018). Kind and Köthenbürger (2018) show that two-sided (digital) market analyses entail non-conventional implications for optimal tax policy. In particular, they find that whereas VAT has no impact on the price in a one-sided, digital market with zero marginal costs, it does impact the price in a two-sided market. Hence, lowering VAT rates in a digital two-sided market could reduce output, contrary to policymakers' intention. Common to both cross-licensing and taxation, the platforms pay a share of their sales revenue, in the latter case in the form of an ad-valorem tax to the government. This paper departs from the tax literature, however, since in the case of cross-licensing, the platform not only pays a royalty to a competitor but also earns a royalty revenue. This changes the strategic considerations of the platforms.

Finally, innovation in the digital economy receives much attention also in non-academic literature. This is due to the importance of digitisation for competition and innovation in markets across all industries, at the same time as public authorities are struggling to regulate digital platforms and enforce digital competition policy in a manner that promotes both innovation and consumer welfare. The OECD has shown interest in both the competitive effects of licensing of intellectual property rights (OECD, 2019) and the competitive effects of digital platforms (see, e.g., OECD, 2009, 2015 and 2022, for a selection of studies on digital market and innovation competition). However, the competitive effects of intellectual property rights in digital markets with strong network effects have not been covered in detail. The rapid development of the digitisation of markets makes it essential to evaluate the competitive effects of the transfer of technology. Understanding the impact of digitisation for innovation and competition is vital to ensuring social welfare for the future.

2.3 The model

2.3.1 Model set-up

The model is depicted in Figure 2.1. There are two differentiated, competing platforms $\{i, j\} = \{A, B\}$ that serve two distinct customer groups $\{k, l\} = \{1, 2\}$. The platforms require access to technologies developed and protected by rivals to produce their services for the customer group on side 1. To access the rival's technology, the platforms sign a cross-licensing contract under which the platforms pay each other a reciprocal royalty, r, on their sales revenue (i.e., ad valorem)

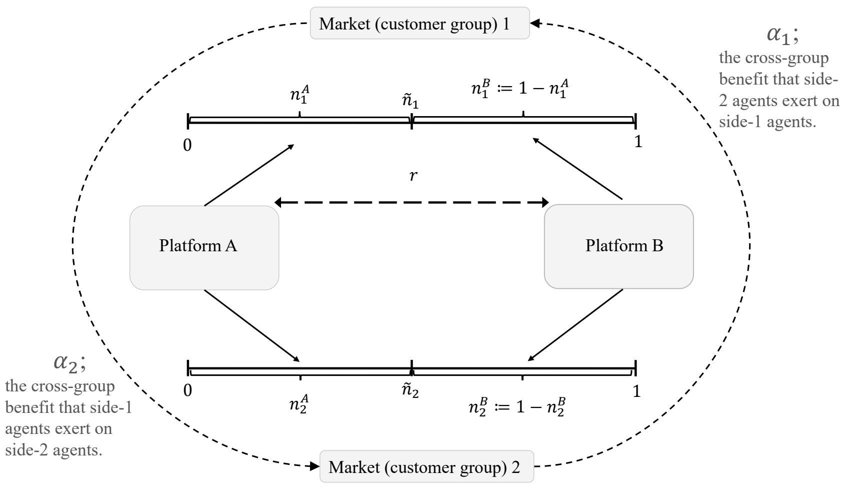

Figure 2.1: The model.

from the sales to the customers on that side of the market.[3] Hence, in the model, the royalty is only levied on side 1 of the market.[4]

Platforms. Platform i's profit under an ad-valorem royalty is:

$$\pi^i = (p_1^i - rp_1^i)n_1^i + p_2^i n_2^i + rp_1^j n_1^j, \tag{2.1}$$

where p_k^i is the price that a side-k agent on platform i pays and n_k^i is the number of agents on each side k who join platform i, i.e., the demand or market share. I normalise—without loss of generality—marginal costs to zero.

Customers. I follow the seminal model of Armstrong (2006) on two-sided markets as a workhorse to derive the customer groups' demand functions. Each of the customer groups forms a Hotelling (1929) line with a length of 1, and users are uniformly distributed along the line.

The utility for an agent on side k of being served by platform A and B, respectively, is given by:

$$u_k^A = v + \alpha_k n_l^A - tn_k^A - p_k^A \quad \text{and} \quad u_k^B = v + \alpha_k n_l^B - tn_k^B - p_k^B, \tag{2.2}$$

[3]Empirical evidence suggests that ad-valorem royalties are the most commonly used licensing mechanism (San Martín and Saracho, 2010).

[4]Consider, for example, the case of SEPs for a technical device, such as a smartphone, that are required to produce the device offered to consumers. The smartphone is a two-sided platform that combines consumers (app users) and app developers, yet the SEP is not related to the platform reaching the app developers.

where v is gross utility, $\{p_k^A, p_k^B\}$ are the respective prices charged by each of the platforms $i = A, B$ to side-k agents, and α_k is the network benefit that a side-k agent enjoys from interacting with each agent on the other side.[5] The platforms are located at each end of the Hotelling line. The customers observe the prices offered by the platforms and form expectations about the size of each customer group on each platform based on these prices. Moreover, assume that the markets on each of the sides are covered (see Assumption 2.1 below), such that $n_k^j := 1 - n_k^i$. A side-k agent located at n_k^A has a mismatch cost of tn_k^A and $tn_k^B = t(1 - n_k^A)$, for platforms A and B, respectively, where $t > 0$ is the differentiation parameter between the two platforms. Setting $u_k^A = u_k^B$ for $k = 1, 2$ (from Equation 2.2), we obtain the number of customers on each side k who join platform i:

$$n_k^i = \frac{1}{2} + \frac{1}{2}\frac{\alpha_k(p_l^j - p_l^i) + t(p_k^j - p_k^i)}{t^2 - \alpha_1\alpha_2}. \tag{2.3}$$

Before proceeding, I make the following three assumptions:

Assumption 2.1 $v > \frac{3t}{2} - (1-r)\alpha_1 + \frac{\alpha_2}{2}$

Assumption 2.2 $4(1-r)t^2 > ((1-r)\alpha_1 + \alpha_2)^2$

Assumption 2.3 $r < \frac{1}{2}$

Assumption 2.1 ensures that markets are covered, Assumption 2.2 ensures that the second-order condition is fulfilled for an inner solution for a maximum, and Assumption 2.3 ensures stability. The derivations behind the assumptions are given in the Appendix.

2.3.2 Benchmark: Cross-licensing in one-sided markets

As a benchmark, I first revisit the anti-competitive effects of cross-licensing in one-sided markets (Katz and Shapiro, 1985; Jeon and Lefouili, 2018). Set $n_2^i = 0$, and lose the subscripts. To access the technology protected by the rival, the firms sign a cross-licensing contract. The profit of firm i is

$$\pi^i = (p^i - rp^i)n^i + rp^j n^j. \tag{2.4}$$

Firm i maximises profits from Equation (2.4) with respect to its own price. By solving $\partial\pi^i/\partial p^i = 0$, the equilibrium price and profits are

[5] For the sake of argument, assume in the rest of the discussion that network effects (α_1, α_2) are positive. In general, network effects could also be negative, although at least one of them must be positive to justify the existence of the platform.

$$p^{i*} = t + \frac{r}{1-2r}t \tag{2.5}$$

and

$$\pi^{i*} = \frac{t}{2} + \frac{r}{2(1-2r)}t. \tag{2.6}$$

The conditions for a stable equilibrium are provided in the Appendix.

Although it is clear from Equation (2.4) that the royalty payments cancel each other out in the symmetric equilibrium, we see from Equation (2.5) that the reciprocal royalty has an impact on the optimal pricing. On the one hand, the firm's profit margin from sales is reduced with the royalty. On the other hand, the firm receives royalty payments from the rival. As a consequence, the sales revenue becomes less important to the firm, and the royalty revenue is relatively more important. The opportunity cost of raising the price is lower, since the loss in sales revenue on the firm's own platform can partially be regained through the increased royalty revenue from the sales on the rival platform. The firms would therefore unilaterally have incentives to increase the price in order to earn a higher royalty revenue. I call this the *competition effect*.

A key insight from one-sided markets is thus that the firms have incentives to increase the price in the presence of a reciprocal royalty. The firms profit at the expense of consumer welfare. Another implication is that the firms have incentives to set the royalty as high as is feasible, since profits unambiguously increase with the royalty.[6]

2.4 Cross-licensing in two-sided markets

I now turn back to the main focus of this paper, namely, cross-licensing in two-sided markets. Equation (2.1) denotes the profit of platform i in a two-sided market with an ad-valorem royalty. Platform i maximises profits from Equation (2.1) with respect to the price for each side of the platform, i.e., each platform i solves

$$\max_{p_k^i, p_l^i} \pi^i. \tag{2.7}$$

For solving the two-sided model with cross-licensing, I first search for the optimal price on each side k on each platform i. The first-order condition of the maximisation problem in Equation (2.7), $\partial \pi^i / \partial p_k^i = 0$, takes on the properties summarised in the following lemma:

Lemma 2.1 *Suppose there are positive cross-group network effects, $\alpha_1, \alpha_2 > 0$. The price reaction functions are*

[6] Recall Assumption 2.3, which constrains how high the firms can set the royalty, $r^* \to \frac{1}{2}$.

(i) increasing across platforms ($\partial p_k^i/\partial p_k^j > 0$ *and* $\partial p_k^i/\partial p_l^j > 0$)*, and*

(ii) decreasing within the platform ($\partial p_k^i/\partial p_l^i < 0$)

Proof. See the Appendix. ■

Lemma 2.1 reproduces the seminal result of Armstrong (2006), and highlights that there are two counteracting effects on the optimal price working against each other. Increasing reaction functions across the platforms implies that the platforms follow each other's prices. If one platform raises its price, the rival platform will follow suit and raise its price as well. Decreasing reaction functions within each platform implies that the platform prices more aggressively towards the side of the platform from which agents from the other side benefit.

Solving for the symmetric equilibrium where each platform offers the same price pair (p_1, p_2) to consumers, the first-order conditions for equilibrium prices yield:[7]

$$p_k(p_l) = t - \frac{\alpha_l}{t}(\alpha_k + p_l + \Delta_k), \tag{2.8}$$

where

$$\Delta_k = \begin{cases} \frac{r}{1-2r}\left[(\alpha_1 + 2p_2) - \frac{t^2}{\alpha_2}\right] & \text{if } k = 1 \\ -2rp_1 & \text{if } k = 2 \end{cases}$$

For derivations, see the Appendix.

The price in Equation (2.8) takes the form of Armstrong (2006), where the price rises with the differentiation parameter and the platform's profit from attracting another agent on the opposite side of the platform. Furthermore, the equations in (2.8) reveal a new element in the price reaction function: cross-licensing in a two-sided market yields an additional interaction (Δ_k) with the royalty, which goes through platform i's profit from attracting an extra group-l agent to the platform. This happens on both sides of the platform, but the signs of the effects are potentially different. In particular, the additional interaction is always negative for $k = 2$, but ambiguous for $k = 1$.

2.4.1 Equilibrium prices

Solving the equations in (2.8) simultaneously, yields the equilibrium prices:

$$p_1^* = t - \alpha_2 + \frac{r}{1-2r}(t - 2\alpha_2) \tag{2.9}$$

[7] Second-order conditions for a stable equilibrium are fulfilled by Assumptions 2.2 and 2.3.

and

$$p_2^* = t - \alpha_1 + r\alpha_1. \tag{2.10}$$

The equilibrium price for group-1 agents can both increase and decrease with r. We see directly from $\frac{\partial p_1}{\partial r} = \frac{t-2\alpha_2}{(1-2r)^2}$ that the sign of the effect of r on the equilibrium price depends on the sign and strength of the network effect. Notice, firstly, that the royalty strengthens the downward push of network effects on prices, $\frac{\partial p_1}{\partial r \partial \alpha_2} < 0$. Next, if there are positive and sufficiently strong network effects ($\alpha_2 > t/2$), the total effect is that the price *falls* with the royalty, implying that the platform might price group-1 agents more aggressively under a cross-licensing regime. This is in contrast to the previous findings about the impact of cross-licensing and royalty contracts in one-sided markets.

The equilibrium price for group-2 agents is moving in the same direction as the cross-group network effect (how much group-1 agents benefit from an extra group-2 agent on the platform), $\frac{\partial p_1}{\partial r} = \alpha_1$. This implies that the equilibrium price for group-2 agents is always increasing in the royalty r if there are positive network effects.

The result can be summarised in the following proposition:

Proposition 2.1 ***(a)*** *The equilibrium price for group-1 agents*

(i) increases less with the royalty when there are positive network effects

(ii) falls in r if network effects are sufficiently strong, $\alpha_2 > t/2$.

(b) *The equilibrium price for group-2 agents is always increasing with the royalty r if there are positive network effects.*

To understand how the price changes with the royalty in the presence of (positive) network effects, note that there are essentially two counteracting effects present: the *competition* effect and the *two-sided* effect. First, by paying a royalty, the platform keeps less of the profit margin from its own sales. At the same time, it obtains an incoming royalty revenue, which the rival pays based on its own sales revenue. The platform's pricing is therefore softer, such that the rival makes a larger revenue since this also entails a higher royalty revenue. The platform can accept lower sales revenue on its own platform, since it is compensated by capturing a share of the rival's sales revenue (through a higher royalty revenue). I call this the *competition effect*, and it is the same cross-licensing mechanism as identified in a one-sided market.

Second, the two-sidedness adds another effect of cross-licensing: by imposing a royalty on one side of the platform, the revenue from this side becomes less important to the platform, and the revenue from the other side of the platform (which carries no royalty) becomes more important. Therefore, when the royalty is levied on side 1, the platform wishes to increase the revenue from side 2. It can increase the revenue from side 2 by attracting more group-1 agents (if there are positive network effects), which implies reducing the price for these agents. This is the *two-sided effect*, which internalises and balances the network effects of the two sides of the market. The effect appears even when there is only an externality from group-1 to group-2 agents (and none the other way around), i.e., $\alpha_1 = 0$ and $\alpha_2 > 0$.

Hence, there are two opposing effects: with the competition effect, the royalty increases the price, while with the two-sided effect, the positive network effect reduces the price increase of the royalty, dampening the anti-competitive harm associated with cross-licensing (part (i) of Proposition 2.1). Moreover, the strength of the cross-group network effect determines the sign of the combined interaction effect of the royalty and network benefits. In particular, if there are strong network effects, $\alpha_2 > t/2$, the combined royalty-network interaction is negative, and the price actually falls with an increase in the royalty (part (ii) of Proposition 2.1). If there are weak network effects, we are left with only the competition effect, and the platform has incentives to increase the price by agreeing on a (high) reciprocal royalty (as in the one-sided benchmark in Section 2.3.2).

The third result (part b) of Proposition 2.1 states that the royalty interacts with the network effect also in the equilibrium price on side 2 (where no royalty is levied) in Equation (2.10). To see why, suppose first that $r = 0$. Here, there is no interaction with the royalty. Second, the larger is r, the more of the platform's sales revenue on side 1 is paid directly to the competing platform. Therefore, the platform should care less about the revenue from side 1, and less about the benefit from side-2 agents to side-1 agents, the larger is r. The cross-group network effect, α_1, should consequently also matter less for the pricing the greater is r. In general, a larger r counteracts the downward pressure of the network effect on the non-royalty levied prices (to side 2).

2.4.2 Equilibrium profits

Inserting the equilibrium prices in Equations (2.9) and (2.10) into the profit function in Equation (2.1) yields the following profits:

$$\pi^i = \underbrace{t}_{\text{Hotelling}} - \underbrace{\frac{\alpha_1 + \alpha_2}{2}}_{\text{two-sided}} + \underbrace{\frac{r}{2}\left[\frac{1}{(1-2r)}(t - 2\alpha_2) + \alpha_1\right]}_{\text{additional royalty-network cost}}. \tag{2.11}$$

The final term in Equation (2.11) represents the cost of the interaction between the royalty and the network effect. This is a novel element of this paper and shows the impact of the network effects on the cross-licensing contract. From Equations (2.9) and (2.10), we see that both of the equilibrium prices contain an additional cost of the interaction between the royalty and network effects. As with the standard Hotelling results, each of the two platforms takes on half of the costs on each side of the platform, including the extra costs due to the royalty payment.

Notice that although strong network effects reduce the equilibrium price, it takes even stronger network effects to reduce the profits. This is because a price reduction on one side of the platform can be regained on the other side of the platform in the presence of network effects. It is only when the network effect is very strong, $2\alpha_2 > t + (1-2r)\alpha_1$, that the higher price for side-2 agents does not compensate for the loss in the lower price for side-1 agents, and equilibrium profits fall with the royalty.

Note also that the profits are falling with network effects from either side of the platform, $\frac{\partial \pi^i}{\partial \alpha_1} = -\frac{1-r}{2} < 0$ and $\frac{\partial \pi^i}{\partial \alpha_2} = -\frac{1}{2(1-2r)} < 0$. This reflects that the stronger the network effects, the more important it is to attract users from the non-levied side, but that the lost royalty revenue on side 1 is not fully compensated by a larger sales revenue on side 2. The decrease will, however, be lower than without the royalty contract.

2.4.3 Optimal cross-licensing with strong network effects

Let us now investigate the optimal cross-licensing contract involving a reciprocal ad-valorem royalty under network effects. Suppose we set up a game in which the platforms first set the reciprocal royalty that maximises profits, before competing over users on both sides of the platform at the final stage. The final-stage profits are then given in the previous section (see Equation 2.11). At the first stage, differentiating profits with respect to r and setting equal to zero,

$$\frac{\partial \pi^i}{\partial r} = \frac{1}{2(1-2r)^2}(t - 2\alpha_2) + \frac{\alpha_1}{2} = 0, \tag{2.12}$$

yields the following proposition:

Proposition 2.2 *If there are strong network effects, $\alpha_2 > t/2$, the optimal reciprocal ad-valorem royalty cross-licensing contract with strong network effects is*

$$r^* = \frac{1}{2} - \frac{\sqrt{\frac{(2\alpha_2 - t)}{\alpha_1}}}{2} < \frac{1}{2}. \tag{2.13}$$

Otherwise, the second-order condition for an inner solution is not satisfied, and the platform will set the royalty as high as is feasible given that markets are served, i.e., $\lim_{\alpha_i \to 0} r^* = \frac{1}{2}$.

Proof. The second-order condition, $\frac{\partial^2 \pi^i}{\partial r^2} = \frac{2(t-2\alpha_2)}{(1-2r)^3} < 0$, is satisfied if, and only if, $\alpha_2 > t/2$. Otherwise, there is no inner solution defined, and $r^* \to \frac{1}{2}$. ∎

Observe that the optimal royalty contract in Proposition 2.2 depends crucially on the strength of the network effect. If there are weak or no cross-group network effects, the platform will set the royalty as high as is feasible given that markets are served and that the royalty level does not lead to monopolisation, $r^* \to \frac{1}{2}$ (cf. the discussion on cross-licensing in one-sided markets in Section 2.3.2). If, however, there are strong network effects, the platform could wish to set the optimal royalty as low as possible, i.e., $r^* \to 0$ might be a potential outcome.[8]

Importantly, this means that the implications of cross-licensing in two-sided markets with cross-group network effects are potentially the opposite to those found in one-sided markets. In a one-sided market, the firms want to set as high a royalty as is feasible to dampen the price competition, whereas two-sided platforms have an additional incentive to balance the revenues from each of the sides it serves, leading to aggressive pricing. The optimal strategy to dampen price competition in a two-sided market is therefore to set a low royalty fee, and more so the stronger the network effects.

2.5 Concluding remarks

Cross-licensing has potentially different implications for the competition in two-sided markets with cross-group network effects than what is known about its competitive effects in one-sided markets. In particular, positive network effects dampen the competitive harm associated with a cross-licensing royalty, and if the network effects are sufficiently strong, the royalty might even incentivise platforms to reduce the price. This stands in contrast to the standard prediction in one-sided markets that cross-licensing will soften competition and raise prices. Consequently, the results from one-sided markets do not necessarily carry over to two-sided markets with cross-group network effects.

These results have important policy implications. At first glance, policymakers should be less concerned about competition harm associated with cross-licensing contracts (with positive royalties) in markets with strong network effects. Rather than being an instrument for raising the rival's costs, the royalty might be used to efficiently balance the revenue from the two sides of the platform. This yields lower prices for customers on the royalty-levied side, to the benefit

[8] Note that the platform could wish to set the optimal royalty as low as possible if network effects are strong, but not too strong; if the network effects are too strong, platform profit could become negative. Imposing non-negative profits, $\pi^i \geq 0$, requires $(2-3r)t - (1-r)(1-2r)\alpha_1 \geq \alpha_2 > t/2$.

of consumers.

Yet this is not to say that there is necessarily less reason to worry. Importantly, prices are often low (or free) on one of the sides of a digital platform, such that the platforms attract more users on the one side in order to monetise on them on the opposite side. As such, policymakers should account for other costs for consumers (outside this model), such as the cost of the potential loss of privacy, when evaluating consumer welfare under cross-licensing.

Finally, I have shown that if the platforms can endogenously choose the optimal reciprocal royalty, royalty-free cross-licensing can be an outcome of the model in the presence of sufficiently strong network effects. Since the equilibrium price falls with the royalty when there are strong cross-group network effects, the profit-maximising action for platforms is to set as low a royalty as is feasible. Indeed, if low or zero royalties are observed, this in itself could be an indication of competition harm, as this practice could dampen price competition in two-sided markets.

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Appendix B

B.1 One-sided equilibrium

In a one-sided market, firm i maximises profits given by Equation (2.4) with respect to its own price, p^i. Firm i's demand is given by the standard Hotelling specification (Equation (2.3), where $\alpha_k = 0$ and with subscripts $k = l$) such that $n^i = \frac{1}{2} + \frac{p^j - p^i}{2t}$ and $n^j = 1 - n^i$. Firm i maximises profits from Equation (2.4). The first-order condition is given by (the second-order condition, $\partial^2\pi^i/\partial(p^i)^2 = -\frac{1}{t}(1-r) < 0$ is satisfied if $r < 1$):

$$\frac{\partial \pi^i}{\partial p^i} = (1-r)n^i + \left[(1-r)p^i\right]\frac{\partial n^i}{\partial p^i} + rp^j\frac{\partial n^j}{\partial p^i} = 0, \tag{B.1}$$

which leads to the best-response functions

$$p^i(p^j) = \frac{t}{2} + \frac{1}{2(1-r)}p^j \text{ for } \{i,j\} = \{A,B\}. \tag{B.2}$$

To ensure stability, I compare the slope of the reaction curves (see Tirole (1988), p. 324). From Equation (B.2), the best-response functions for firm A and B, respectively, are

$$R^A : p^A(p^B) = \frac{t}{2} + \frac{1}{2(1-r)}p^B \tag{B.3}$$

and

$$R^B : p^B(p^A) = \frac{t}{2} + \frac{1}{2(1-r)}p^A. \tag{B.4}$$

By reformulating R^A and expressing both best responses as functions of p^A, we can rewrite the reaction functions as

$$R^A : p^B(p^A) = 2(1-r)p^A - \frac{t}{2}$$

and

$$R^B : p^B(p^A) = \frac{1}{2(1-r)}p^A + \frac{t}{2}.$$

To ensure a stable equilibrium, the slope of the reaction function R^A must be larger than the slope of the reaction function R^B, i.e., $2(1-r) > \frac{1}{2(1-r)}$. This is satisfied for $r < 1/2$. Assumption 2.3 follows and ensures a stable equilibrium.

Finally, solving the best-response functions in Equation (B.2) simultaneously, I find the one-sided equilibrium price

$$p^{i*} = t + \frac{r}{1-2r}t. \tag{B.5}$$

Equation (B.5) corresponds to Equation (2.5).

Note that absent of any royalty fee, $r = 0$, the equilibrium price is the standard Hotelling equilibrium, $p^{i*}|_{r=0} = t$. Next, the equilibrium price increases with the royalty, $\partial p^{i*}/\partial r = t/(1-2r)^2 > 0$.

Inserting the equilibrium prices from Equation (2.5) into the profit function of Equation (2.4), equilibrium profit is given by:

$$\pi^{i*} = \frac{t}{2} + \frac{r}{2(1-2r)}t, \tag{B.6}$$

which also increases with the royalty, $\partial \pi^{i*}/\partial r = \frac{t}{2(1-2r)^2} > 0$ (as long as Assumption 2.3 holds).

B.2 Market coverage

I will now return to the two-sided model. Markets are covered if all customers buy. Since the customer with lowest utility is the indifferent consumer, a market is covered if the indifferent customer buys, i.e., if $u_k^i > 0$. The utility is given by Equation (2.2), where n_k^i is given by Equation (2.3) and $n_k^j = 1 - n_k^i$, and $p_k^i = p_k^j = p_i$ are given by Equations (2.9) and (2.10), for all $k, l = 1, 2$ and $i, j = A, B$.

Market 1 is covered if $u_1^i > 0$:

$$v > \frac{3t}{2} + \frac{\alpha_1}{2} - \alpha_2 + \frac{r}{1-2r}(t - 2\alpha_2), \tag{B.7}$$

and market 2 is covered if u_2^i:

$$v > \frac{3t}{2} - (1-r)\alpha_1 + \frac{\alpha_2}{2}. \tag{B.8}$$

If the cross-group network benefit is sufficiently strong for side 2 from having side-1 agents on the platform (α_2 is large), constraint (B.8) will be the strictest, and is therefore the required assumption for market coverage (Assumption 2.1).

B.3 Proof of Lemma 2.1

Inserting the market shares from Equations in (2.3) into the profit function in Equation (2.1), yields

$$\begin{aligned}\pi^i = (p_1^i - rp_1^i)&\left[\frac{1}{2} + \frac{1}{2}\frac{\alpha_1(p_2^j - p_2^i) + t(p_1^j - p_1^i)}{t^2 - \alpha_1\alpha_2}\right] \\ &+ p_2^i\left[\frac{1}{2} + \frac{1}{2}\frac{\alpha_2(p_1^j - p_1^i) + t(p_2^j - p_2^i)}{t^2 - \alpha_1\alpha_2}\right] \\ &+ rp_1^j\left[1 - \left(\frac{1}{2} + \frac{1}{2}\frac{\alpha_1(p_2^j - p_2^i) + t(p_1^j - p_1^i)}{t^2 - \alpha_1\alpha_2}\right)\right].\end{aligned} \tag{B.9}$$

By differentiating the profit function with respect to p_k^i, we find the first-order conditions

$$\begin{aligned}\frac{\partial \pi^i}{\partial p_1^i} = (1-r)&\left(\frac{t^2 - \alpha_1\alpha_2 + (p_2^j - p_2^i)\alpha_1 + t(p_1^j - p_1^i)}{2(t^2 - \alpha_1\alpha_2)}\right) \\ &- \frac{p_1^i(1-r)t}{2(t^2 - \alpha_1\alpha_2)} - \frac{p_2^i\alpha_2}{2(t^2 - \alpha_1\alpha_2)} + \frac{rp_1^j t}{2(t^2 - \alpha_1\alpha_2)} = 0\end{aligned} \tag{B.10}$$

and

$$\begin{aligned}\frac{\partial \pi^i}{\partial p_2^i} = &\frac{t^2 - \alpha_1\alpha_2 + (p_1^j - p_1^i)\alpha_2 + t(p_2^j - p_2^i)}{2(t^2 - \alpha_1\alpha_2)} \\ &- \frac{p_1^i(1-r)\alpha_1}{2(t^2 - \alpha_1\alpha_2)} - \frac{p_2^i t}{2(t^2 - \alpha_1\alpha_2)} + \frac{rp_1^j\alpha_1}{2(t^2 - \alpha_1\alpha_2)} = 0.\end{aligned} \tag{B.11}$$

From the first-order conditions, we obtain the following best-response functions:

$$p_1^i(p_1^j, p_2^i, p_2^j) = \frac{t^2 - \alpha_1\alpha_2 + (p_2^j - p_2^i)\alpha_1}{2t} + \frac{p_1^j}{2(1-r)} + \frac{p_2^i\alpha_2}{2t(1-r)} \tag{B.12}$$

and

$$p_2^i(p_1^i, p_1^j, p_2^j) = \frac{t^2 - \alpha_1\alpha_2 + (-(1-r)p_1^i + rp_1^j)\alpha_1 + \alpha_2(p_1^j - p_1^i)}{2t} + \frac{p_2^j}{2}. \tag{B.13}$$

It follows from the best-response functions in Equations (B.12) and (B.13) that

(i) $\frac{\partial p_1^i}{\partial p_1^j} = \frac{1}{2(1-r)} > 0$ and $\frac{\partial p_2^i}{\partial p_2^j} = \frac{1}{2} > 0$,

(ii) $\frac{\partial p_1^i}{\partial p_2^j} = \frac{\alpha_1}{2t} > 0$ and $\frac{\partial p_2^i}{\partial p_1^j} = \frac{r\alpha_1 + \alpha_2}{2t} > 0$,

(iii) $\frac{\partial p_1^i}{\partial p_2^i} = -\frac{(1-r)\alpha_1 + \alpha_2}{2t(1-r)} < 0$ and $\frac{\partial p_2^i}{\partial p_1^i} = -\frac{(1-r)\alpha_1 + \alpha_2}{2t} < 0$

if $\alpha_1, \alpha_2 > 0$. That is, in the presence of positive cross-group network effects, the price reaction functions are increasing across platforms (i-ii), but decreasing within a platform, across sides (iii). ■

B.4 The existence of stable, symmetric equilibrium

In this appendix, I derive the conditions for a stable equilibrium when each platform offers the same price pair (p_1, p_2) to consumers. The first-order condition is given by Equation (2.8).

Second-order conditions To ensure that the second-order conditions of the maximisation problem (2.7) are fulfilled, the first-order and second-order principal minor determinants of the Hessian matrix,

$$\mathbf{H}_{\pi^i} = \begin{bmatrix} \frac{\partial^2 \pi^i}{\partial (p_1^i)^2} & \frac{\partial^2 \pi^i}{\partial p_1^i \partial p_2^i} \\ \frac{\partial^2 \pi^i}{\partial p_2^i \partial p_1^i} & \frac{\partial^2 \pi^i}{\partial (p_2^i)^2} \end{bmatrix} = \begin{bmatrix} -\frac{(1-r)t}{t^2-\alpha_1\alpha_2} & -\frac{(1-r)\alpha_1+\alpha_2}{2(t^2-\alpha_1\alpha_2)} \\ -\frac{(1-r)\alpha_1+\alpha_2}{2(t^2-\alpha_1\alpha_2)} & -\frac{t}{t^2-\alpha_1\alpha_2} \end{bmatrix},$$

must be negative and positive, respectively. The determinant of first-order principal minor is $det(H_1) = \frac{\partial^2 \pi^i}{\partial (p_1^i)^2} = -\frac{(1-r)t}{t^2-\alpha_1\alpha_2} < 0$ if $t^2 > \alpha_1\alpha_2$. The determinant of second-order principal minor is $det(H_2) = \frac{\partial^2 \pi^i}{\partial (p_1^i)^2}\frac{\partial^2 \pi^i}{\partial (p_2^i)^2} - (\frac{\partial^2 \pi^i}{\partial p_1^i \partial p_2^i})^2 = \frac{4(1-r)t^2-((1-r)\alpha_1+\alpha_2)^2}{4(t^2-\alpha_1\alpha_2)^2} > 0$. Assumption 2.2 follows, and ensures that the Hessian is negative definite, such that the second-order condition is fulfilled and we have a maximum.

Stability To ensure that the equilibrium is indeed stable, we must investigate the reaction functions in more detail (see Tirole (1988), p. 324). The first-order conditions for equilibrium prices are given by Equation (2.8) for side $\{k, l\} = \{1, 2\}$. By expressing both reaction functions as functions of p_1, we can rewrite the reaction functions as:

$$R_1 : p_2(p_1) = \frac{t}{\alpha_2}[t(1-r) - (1-2r)p_1] - \alpha_1(1-r)$$

and

$$R_2 : p_2(p_1) = t - \frac{\alpha_1}{t}(\alpha_2 + (1-2r)p_1).$$

To ensure a stable equilibrium, we require the slope of the reaction function R_1 to be larger than the slope of the reaction function R_2, i.e., $(1-2r)\frac{t}{\alpha_2} > (1-2r)\frac{\alpha_1}{t}$. This is satisfied for $r < 1/2$. Assumption 2.3 follows and ensures a stable equilibrium.

Chapter 3

Size-based wholesale price discrimination under endogenous inside options

Chapter 3

Size-based input price discrimination under endogenous inside options*

Charlotte Bjørnhaug Evensen[a], Øystein Foros[b], Atle Haugen[b] and Hans Jarle Kind[a,c]

[a] Department of Economics
[b] Department of Business and Management Science
[c] CESifo

NHH Norwegian School of Economics

Abstract

Individual retailers may choose to invest in a substitute to a dominant supplier's products (inside option) as a way of improving its position towards the supplier. Given that a large retailer has stronger investment incentives than a small retailer, a large retailer may obtain a selective rebate (size-based price discrimination). We study the incentives of dominant suppliers to commit to uniform pricing in wholesale markets. The seminal literature on wholesale price discrimination has provided clear-cut results when the source of wholesale price discrimination is inside options: a dominant supplier will commit to uniform wholesale pricing, and consumers will be harmed. In a model with endogenous inside options and differentiated retailers, we show that the outcome is ambiguous. We confirm the result if retailers are close substitutes. If, however, the retailers are weak substitutes, the outcome flips around. Consumers are better off under uniform pricing, but the supplier has no incentives to commit to uniform pricing. Interestingly, for an intermediate level of substitutability among the retailers, supplier and consumer interests can coincide.

Keywords: Input price discrimination, size asymmetries, retail competition, inside options.
JEL classifications: D21, L11, L13.

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E-mail adresses: charlotte.evensen@nhh.no, oystein.foros@nhh.no, atle.haugen@nhh.no and hans.kind@nhh.no.

3.1 Introduction

Size-based wholesale price discrimination in favor of large retailers is an age-old issue and takes place in a large array of industries. Walmart's success, for instance, has been partly explained by the advantageous wholesale prices it has enjoyed due to its size (see e.g. Basker, 2007; Ellickson, 2016; Dukes, Gal-Or, and Srinivasan, 2006); a ten percent increase in volume reduces Walmart's marginal upstream costs by two percent (Basker, 2007). Likewise, Amazon exploits its power as a large retailer to obtain low wholesale prices in the book-publishing market (Gilbert, 2015), and in the US multi-channel television market, the per-customer wholesale prices for a large firm like Comcast could be 25 percent lower than those faced by smaller firms (Crawford and Yurukoglu, 2012; Doudchenko and Yurukoglu, 2016). Finally, the UK competition authorities found a significant negative relationship between size in grocery retailing and unit wholesale prices (Competition Commission, 2008).[1]

Individual retailers may threaten to switch to an alternative source of supply instead of buying the product from the dominant supplier. If this is credible, the dominant supplier must lower the wholesale price to keep the retailer onboard. If one retailer has better access to an alternative than the other retailer, the supplier will price discriminate in favor of this retailer. However, it is not obvious that the supplier wants to price discriminate. In this paper, we investigate under what conditions a dominant supplier benefits from price discrimination, and when the supplier prefers to commit to uniform pricing. To analyze this, we set up a simple model for a wholesale market. There are two identical and independent local markets. A small retailer is present in each local market, while a large retailer has an outlet in both markets. We allow the retailers to be differentiated. The retailers are offered a product from a dominant supplier that they can resell to the consumers. Prior to the supplier's decision on wholesale prices, the retailers may invest in reducing the marginal costs of an alternative to the supplier's product, in order to put pressure on the supplier to lower wholesale prices. We label this alternative as an "inside option". Investing in marginal-cost reductions on the inside option is more profitable for the large retailer, all else equal, since it benefits from larger marginal benefits in total for all the locations in which it operates. The model thus endogenizes the inside option, resulting in inside option asymmetries and, consequently, size-based wholesale price discrimination in favor of the largest retailer.

We find that the supplier is worse off, whereas consumers benefit from price discrimination if

[1]The Norwegian Competition Authority (2019) conducted a comprehensive study of wholesale prices in the grocery market. From 14 out of the 16 suppliers investigated—most of them dominant suppliers—the largest retail chain obtains a selective unit cost rebate (the differences were in the range 0–10 percent from 10 suppliers, 10–15 percent from three suppliers, and above 15 percent from one supplier).

the retailers are sufficiently close substitutes. For a low level of substitutability among retailers, the outcome flips around. If the substitutability becomes sufficiently small, the consumers benefit if the supplier commits to uniform pricing (or restrictions on price discrimination are imposed by the authorities), but the supplier has no incentives to make such a commitment. Interestingly, however, for an intermediate level of substitutability, supplier and consumer interests can coincide.

The intuition for the results is as follows. Since a large retailer has stronger incentives to invest in inside options than a smaller retailer, a smaller retailer is therefore, under uniform pricing, free-riding on the large retailer's investment in inside options, and consequently never invest under uniform pricing. When the retailers are unrelated, the investment, and consequently the wholesale price for the large retailer, is equal under uniform pricing and price discrimination. The small retailers will obtain the same wholesale price as the large retailer under uniform pricing, but the (higher) unconstrained wholesale price under price discrimination. This explains why consumers are better off with uniform pricing when the substitutability among the retailers becomes sufficiently small.

As the retailers become closer substitutes, the large retailer will invest more under price discrimination (business-stealing) and less under uniform pricing (since the investment spillover makes the smaller rivals more aggressive). A commitment to uniform pricing reduces the retailers' investment incentives (ex ante), which allows the supplier to raise its wholesale price. Consequently, uniform pricing becomes relatively more attractive for the supplier as the retailers become closer substitutes. This explains why the incentives of the supplier shift, and that supplier and consumer interests therefore can coincide for an intermediate level of substitutability.

Thereby we complement earlier contributions on who benefits from size-based wholesale price discrimination. The literature shows that this critically depends on whether the source of such price discrimination is related to inside or outside options. Akgün and Chioveanu (2019) consider investments in inside options, in a model that is closely related to ours, and find consumers are better off—while the supplier is worse off—if the supplier can price discriminate. Consequently, the supplier would benefit from the ability to commit to uniform pricing. In contrast to us, however, Akgün and Chioveanu (2019) consider symmetric retailers. In their equilibrium, the retailers have the same investment incentives, and therefore choose the same investment level and pay the same wholesale price. Consequently, both retailers prefer price discrimination over uniform pricing. Since the retailers' investments are the same, the supplier would be indifferent between price discrimination and uniform pricing when the retailers are unrelated. Consequently, Akgün and Chioveanu (2019) show that their result holds for all levels of substitutability. We show how this changes when the retailers differ in size.

Retailers can also invest in outside options after the wholesale prices have been determined. As long as the outside option is binding for at least the larger retailer, Katz (1987) show that consumers are better off under uniform pricing, while the supplier prefers to have the ability to price discriminate.[2] The reason is that the threat of choosing the outside option does not disappear if the supplier cannot use price discrimination, and the supplier needs to provide a lower wholesale price to all retailers to ensure that the large retailer does not go for the outside option. O'Brien (2014) extends the framework of Katz (1987) to a bargaining framework. If an outside option is binding, his results resemble those of Katz (1987). If the source of price discrimination instead is (exogenously given) asymmetries in inside options, and the outside option is not binding, the supplier prefers uniform pricing, while consumers are better off with price discrimination.

Size-based wholesale price discrimination has been a controversial antitrust issue dating back to the Robinson-Patman Act of 1936. Katz (1987), O'Brien (2014), and Akgün and Chioveanu (2019) leave us with some clear-cut results that seemingly provide a simple rule of thumb for competition authorities:[3] Dig into the source of size-based price discrimination. If it becomes apparent that the source relates to outside options, further analyses should be undertaken, since consumers may be harmed. In contrast, if the source of size-based price discrimination relates to inside options, pressure from, e.g., small retailers, to put restrictions on suppliers' ability to use price discrimination should be dismissed. We show that this finding is too simplistic, however, even if the source of size-based price discrimination is inside options.[4]

3.2 The model

We consider a setting with two identical and independent local markets, $k = \{A, B\}$. In each market, k, there is a small retailer, S, which only operates locally. There is also a large retailer, L, which is present in both markets. A dominant upstream supplier, U, offers each retailer a

[2] The large retailer prefers price discrimination, while the smaller retailer prefers uniform pricing under both inside and outside options.

[3] In contrast to us, both Katz (1987) and O'Brien (2014) consider Cournot competition, where the retailers are perfect substitutes.

[4] Large retailers may also achieve a rebate compared to smaller retailers if it faces increasing marginal costs in the relevant area (Chipty and Snyder, 1999, and subsequent papers). Asymmetries in retail efficiency, however, cannot explain size-based price discrimination in favor of the large retailer. Quite the opposite; DeGraba (1990), Katz (1987), and Akgün and Chioveanu (2019) show that an unconstrained supplier will price discriminate in favor of the less efficient retailer. If the retailers can invest prior to the decision on wholesale prices to reduce retail marginal costs, DeGraba (1990) shows that retailers invest less under price discrimination than under uniform pricing. The reason is that the more a retailer invests in retail marginal-cost reductions, the greater the level of price discrimination in disfavor of the more efficient retailer. In our set-up, we deliberately assume that retailers are equally efficient at the retail level. Consequently, differences in retail marginal costs are not a source of price discrimination in our model.

product that it can resell to the consumers. If retailer $i = \{S, L\}$ buys the product from the supplier, it is charged a unit wholesale price, w_i, by the supplier.[5] We normalize retailing costs to zero.

Rather than buying from the supplier, retailer i can produce a substitutable product in-house if it has previously made an adequate investment. In the words of O'Brien (2014), the retailer thus has an inside option. Let o_i denote the marginal cost of producing this inside option:

$$o_i = c - x_i, \text{ where } i, j = S, L; i \neq j, \tag{3.1}$$

where c is the gross marginal cost, and x_i reflects the investment in marginal-cost reduction by retailer i. The net profit of the small and large retailers, respectively, are

$$\pi_S = (p_S^k - z_S^k)q_S^k - C(x_S) \tag{3.2}$$

and

$$\pi_L = (p_L^A - z_L^A)q_L^A + (p_L^B - z_L^B)q_L^B - C(x_L), \tag{3.3}$$

where $z_i = \min\{w_i, o_i\}$. The cost of investing in a marginal-cost reduction of x_i is $C(x_i)$, where C is strictly increasing and strictly convex, $C' > 0, C'' > 0$. More specifically, we define $C(x_i)$ in the following way:

$$C(x_i) = \frac{\gamma}{2}x_i^2. \tag{3.4}$$

We normalize all costs for the supplier to zero, so that its profit level in each local market is

[5]While real-world contracts typically involve more than a simple unit wholesale price, linear wholesale pricing seems to be a more reasonable assumption than non-linear contracts in many markets. One example is grocery retailing. Even though the contracts between suppliers and retailers are complex, comprehensive investigations by competition authorities in the UK and Norway (Competition Commission, 2008; Norwegian Competition Authority, 2019) reveal that rebates are given at the margin and that (average) variable wholesale price components are decreasing in size (see also discussion by Inderst and Valletti, 2009). Linear wholesale price contracts are also widely used in cable television markets (Crawford and Yurukoglu, 2012; Crawford et al., 2018; Doudchenko and Yurukoglu, 2016) and in the book-publishing industry (see e.g. Gilbert, 2015). Further examples are provided by Gaudin (2019). Iyer and Villas-Boas (2003) provide a theoretical rationale for using linear wholesale pricing. Under non-linear pricing, whether or not wholesale contracts are secret is a crucial consideration. Under secret contracts, O'Brien and Shaffer (1992; 1994) show that there will be no price discrimination at the margin from an unconstrained supplier. Instead, wholesale prices at the margin equal the supplier's marginal cost. In contrast to the outcome under non-linear pricing, Gaudin (2019) shows that consumer prices may be higher under secret than under observable (and credible) linear wholesale prices. Most of the papers on wholesale price discrimination under non-linear contracts assume an unconstrained supplier. One exception is Inderst and Shaffer (2019), who show that if retailers have access to outside options, the supplier may reduce the unit wholesale price, and increase the fixed slotting fee, towards one of the retailers, thereby reducing the value of the outside options for all other retailers.

given by:

$$u = w_S q_S + w_L q_L. \tag{3.5}$$

In each local market, consumer preferences are defined by a Shubik-Levitan (1980) utility function:[6]

$$\Psi(q_S^k, q_L^k) = 2(q_S^k + q_L^k) - (1-s)\Big(\left(q_S^k\right)^2 + \left(q_L^k\right)^2\Big) - \frac{s}{2}(q_S^k + q_L^k)^2,$$

where $s \in [0,1]$ reflects the degree of substitutability between the outlets. Consumer surplus in a representative market is given by

$$CS = \Psi(q_S^k, q_L^k) - p_S^k q_S^k - p_L^k q_L^k. \tag{3.6}$$

Solving $\partial CS/\partial q_i^k = 0$, we find the inverse demand functions

$$p_i^k = 2 - (1-s)2q_i^k - s(q_S^k + q_L^k).$$

The timing of the game is as follows:

- Stage 1: The retailers decide how much to invest in the inside option (S and L choose x_S and x_L, respectively).
- Stage 2: The supplier sets the wholesale prices: (i) w_S^{PD} and w_L^{PD} under price discrimination (PD) and (ii) w^{UP} under uniform pricing (UP).
- Stage 3: Cournot competition in each local market. S and L choose q_S^k and q_L^k, respectively.

The game is solved by backward induction.

Our aim here is to focus on who benefits from uniform pricing. If the supplier benefits, we may expect it to commit to uniform pricing, if it is abile to do so. A commitment to uniform pricing could, for instance, be achieved by signing a wholesale most-favored nation (MFN) clause with a small retailer. If consumers benefit from uniform pricing, an important policy issue is thus whether the authorities should restrict the supplier's ability to price discriminate.

[6]The demand system by Shubik and Levitan (1980) has an attractive property, as it enables us to vary the degree of substitution among retailers without affecting the size of the market (see e.g., the discussion in Inderst and Shaffer, 2019).

It is straightforward to show that if the inside options are non-binding for both retailers, which means there will be no investments (NI), the solution of $\max_{w_S, w_L} u$ gives the following unconstrained equilibrium:[7]

$$w^{NI} = 1 \text{ and } q^{NI} = \frac{1}{4-s}. \tag{3.7}$$

To ensure that the retailers buy from the supplier if there are no investments, we make the following assumption throughout the paper:

Assumption 3.1 $c > \underline{c} = 1$.

Furthermore, we want to avoid the trivial unconstrained case given by Equation (3.7). The large retailer has several outlets. Investing in reducing the marginal costs on the inside option is therefore more profitable for the large retailer, all else equal, since it benefits from larger marginal benefits in total for all the locations in which it operates. Therefore, the inside option must bind for at least the large retailer. In the basic model, we further assume that the inside option is binding for only the large retailer:

Assumption 3.2 $c \in (\bar{c}_S, \bar{c}_L]$,

where

$$\bar{c}_L = 2 - \frac{\sqrt{\gamma(9\gamma - 4)}}{3\gamma} \text{ and } \bar{c}_S = 2 - \sqrt{\frac{4\gamma - 1}{4\gamma}}. \tag{3.8}$$

In Appendix C.4, we show that $c \leq \bar{c}_L$ is a sufficient condition to ensure that the inside option is binding for the large retailer. The condition $c > \bar{c}_S$ is sufficient to ensure that the small retailer does not invest. We relax the latter assumption in an extension (Section 3.3).

Further, we assume the following throughout the paper:

Assumption 3.3 $\gamma > \frac{8}{3}$.

Assumption 3.3 is the sufficient condition for second-order conditions and stability in equilibrium.

[7] Hence, we have $\pi_S^{NI} = (2-s)\left(q^{NI}\right)^2$, $\pi_L^{NI} = 2\pi_S^{NI}$. Profit to the supplier in each local market is $u^{NI} = 2q^{NI}$.

3.2.1 Stage 3: Cournot

By solving $\partial \pi_S / \partial q_S^k = 0$ and $\partial \pi_L / \partial q_L^k = 0$ from (3.2) and (3.3), respectively, we find the equilibrium output in each local market k:

$$q_i^k = \frac{2(4-3s) - 2(2-s) z_i + s z_j}{(4-s)(4-3s)}. \tag{3.9}$$

Since the local markets are identical, we may now for simplicity define $p_i^A = p_i^B \equiv p_i$ and $q_i^A = q_i^B \equiv q_i$. This allows us to write the net profit of a representative small retailer and the large retailer, respectively, as

$$\pi_S = (2-s) q_S^2 - C(x_S) \tag{3.10}$$

and

$$\pi_L = 2(2-s) q_L^2 - C(x_L). \tag{3.11}$$

Recall from Assumption 3.2 that the small retailer does not invest in the basic model.

3.2.2 Stage 2: The supplier decides wholesale prices

The wholesale price towards the large retailer is $w_L^R = c - x_L^R$, where $R \in \{UP, PD\}$. Under uniform pricing, both retailers are charged $w^{UP} = w_L^{UP}$. Under price discrimination, the large retailer is charged

$$w_L^{PD} = o_L.$$

To find the wholesale price for the small retailer, the supplier solves

$$\max_{w_S} u \text{ s.t. } w_L^{PD} = o_L,$$

and w_S^{PD} becomes:

$$w_S^{PD} = w^{NI} - \frac{s}{2(2-s)} \left(w^{NI} - \left(c - x_L^{PD}\right)\right). \tag{3.12}$$

A crucial mechanism is identified in Equation (3.12). If the consumers perceive the retailers as unrelated, $s = 0$, the supplier charges the small retailer the unconstrained wholesale price $w^{NI} = 1$ (from Equation (3.7)). However, if $s > 0$, the supplier will reduce w_S^{PD} below w^{NI} as long as $w^{NI} > c - x_L^{PD}$. The more the large retailer invests, the lower is $w_L^{PD} = c - x_L^{PD}$, and the more the supplier will reduce w_S^{PD}. The binding inside option for L forces the supplier to reduce w_L^{PD} as x_L^{PD} increases. Consequently, the supplier's margin is higher for sales through S than L.

To transfer sales from L to S, the supplier lowers w_S^{PD}. More specifically, from Equation (3.12), we have:

$$\frac{\partial w_S^{PD}}{\partial x_L^{PD}} = -\frac{s}{2(2-s)} < |1| \text{ and } \frac{\partial w_S^{PD}}{\partial x_L^{PD} \partial s} = -\frac{1}{(2-s)^2} < 0.$$

Hence, we obtain the following result:

Proposition 3.1 *Assume price discrimination. The supplier will lower the wholesale price for the small retailer, the more the large retailer invests, $\partial w_S^{PD}/\partial x_L^{PD} < 0$ if $s > 0$, and more so the closer rivals are the retailers, $\partial w_S^{PD}/(\partial x_L^{PD} \partial s) < 0$.*

3.2.3 Stage 1: Investments in inside options

Uniform pricing

By inserting for $w^{UP} = c - x_L^{UP}$ into Equation (3.9) and solving $\partial \pi_L^{UP}/\partial x_L^{UP} = 0$, we find the investment and the wholesale price:

$$x_L^{UP} = \frac{2-c}{2\gamma - 1} - \frac{s^2 \gamma (2-c)}{(2\gamma - 1)\Omega} \text{ and } w^{UP} = c - x_L^{UP}, \tag{3.13}$$

where $\Omega = 8((\gamma - 1) + \gamma(1-s)) + s(4 + s\gamma)$. The investment is decreasing in s, such that the wholesale price is increasing in s:

$$\frac{\partial x_L^{UP}}{\partial s} = -\frac{4s\gamma(2-c)(4-s)}{\Omega^2} < 0 \longrightarrow \frac{\partial w^{UP}}{\partial s} > 0. \tag{3.14}$$

The investment spillover identified in Proposition 3.1 does not matter to the large retailer if $s = 0$. In contrast, when the retailers compete, $s > 0$, the spillover makes the rival more aggressive, and more so the larger is s. Hence, investments from the large retailer are decreasing in s.[8]

[8] The sufficient critical value $\bar{c}_L$ that ensures that the inside option is binding for the large retailer—Assumption 3.2 above—follows from setting $\pi_{L,s=1}^{UP} = \pi_{s=1}^{NI}$. As we show, the large retailer has higher investment incentives under price discrimination. Hence, $c \leq \bar{c}_L$ ensures that the inside option is binding for the large retailer in all regimes.

Price discrimination

By inserting w_S^{PD} from (3.12) and $w_L^{PD} = c - x_L^{PD}$ into Equation (3.9), and solving $\partial \pi_L^{PD} / \partial x_L^{PD} = 0$, we find

$$x_L^{PD} = \frac{2-c}{2\gamma - 1} + s\frac{1 + \gamma(2-s) - \gamma(4-s)(c-1)}{(2\gamma-1)\Phi} \text{ and } w_L^{PD} = c - x_L^{PD}, \tag{3.15}$$

where $\Phi = (4-s)((\gamma-1) + \gamma(1-s))$.

The first term in the square bracket is identical to the first term in Equation (3.13). This reflects that the investment level is identical under uniform pricing and price discrimination when the retailers are unrelated ($s = 0$). In contrast with the outcome under uniform pricing, we now find that the x_L^{PD} is increasing in s, such that w_L^{PD} is decreasing in s:[9]

$$\frac{\partial x_L^{PD}}{\partial s} > 0 \rightarrow \frac{\partial w_L^{PD}}{\partial s} < 0. \tag{3.16}$$

The wholesale price towards the small retailer becomes

$$w_S^{PD} = w^{NI} - s\frac{2 - \gamma(4-s)(c-1)}{2\Phi}, \tag{3.17}$$

such that the small retailer is charged the unconstrained outcome $w^{NI} = 1$ if $s = 0$. As expected, w_S^{PD} decreases in s:[10]

$$\frac{\partial w_S^{PD}}{\partial s} < 0. \tag{3.18}$$

3.2.4 Comparison

By comparing wholesale prices under uniform pricing and price discrimination, we find:

[9] It is straightforward to show that

$$\frac{\partial x_L^{PD}}{\partial s} = -\frac{\bar{c}_L \gamma (4-s)^2}{\Phi^2} + \frac{24\gamma - 16s\gamma + 3s^2\gamma + 4}{\Phi^2} > 0.$$

[10] Differentiating Equation (3.17) with respect to s, we have: $\frac{\partial w_S^{PD}}{\partial s} = -\frac{2-\gamma(4-s)(c-1)}{2\Phi} - \frac{s}{2}\left(\frac{\gamma(c-1)}{\Phi} - \frac{2-\gamma(4-s)(c-1)}{\Phi^2}\frac{\partial \Phi}{\partial s}\right)$, where $\frac{\partial \Phi}{\partial s} = -((\gamma-1) + \gamma(5-2s)) < 0$. Hence, both terms are negative, such that $\frac{\partial w_S^{PD}}{\partial s} < 0$.

Proposition 3.2 *(i) Assume that the retailers are unrelated ($s = 0$): The wholesale price for the large retailer is equal under uniform pricing and price discrimination. The small retailers will obtain the same wholesale price as the large retailer under uniform pricing, but the (higher) unconstrained wholesale price under price discrimination, $w^{UP}_{s=0} = w^{PD}_{L,s=0} < w^{PD}_{S,s=0} = w^{NI} = 1$.*
(ii) Assume that the retailers are substitutes ($s \in (0, 1]$): The uniform wholesale price is increasing with the level of substitutability, whereas the discriminatory wholesale prices for both retailers are decreasing with the level of substitutability, $\frac{\partial w^{UP}}{\partial s} > 0$, $\frac{\partial w^{PD}_L}{\partial s} < 0$, $\frac{\partial w^{PD}_S}{\partial s} < 0$.

Proof. Part (i) follows from (3.13), (3.15), (3.17), and (3.7). Part (ii) follows from (3.14), (3.16), and (3.18). ■

Let us first discuss part (i) of Proposition 3.2, where retailers are unrelated ($s = 0$). When there is no retail competition, the large retailer's investment level is independent of the pricing regime. Consumers buying from L are not affected by the pricing regime, and the supplier's profit from sale through L is also identical in both pricing regimes. The effect of uniform pricing is purely to reduce the wholesale price for the small retailer. Both the small retailer and its consumers are better off under uniform pricing. Consequently, we have the following corollary from Proposition 3.2:

Corollary 3.1 *Assume that the retailers are unrelated ($s = 0$): Consumers are better off under uniform pricing, while the supplier is better off with price discrimination.*

The supplier will therefore not want to commit to uniform pricing when the retailers offer unrelated products ($s = 0$). Hence, we do not expect uniform pricing to arise without intervention from the authorities when $s = 0$.

When s increases, we can see from part (ii) of Proposition 3.2 that the wholesale prices go in opposite directions in the two regimes. We illustrate how the wholesale prices change with s in Figure 3.1.[11] The horizontal axis measures the degree of substitutability, s, ranging from 0 (unrelated) to 1 (perfect substitutes). On the vertical axis are the wholesale prices in each regime. The wholesale price is increasing in s under uniform pricing, while the wholesale prices are decreasing in s for both retailers under price discrimination. To elucidate, if the supplier price discriminates, the large retailer will have higher investment incentives the stronger the retail competition. Larger investments force the supplier to reduce the wholesale price to the large retailer. From Proposition 3.1, we also know that some of these investments will spill over and

[11]The figure is illustrated with the parameter values $c = 1.025$ and $\gamma = 8$, which ensure that $c \in (max\{\underline{c}, \overline{c}^{PD}_S\}, \overline{c}^{UP}_L]$, such that the inside option is only binding for the large retailer.

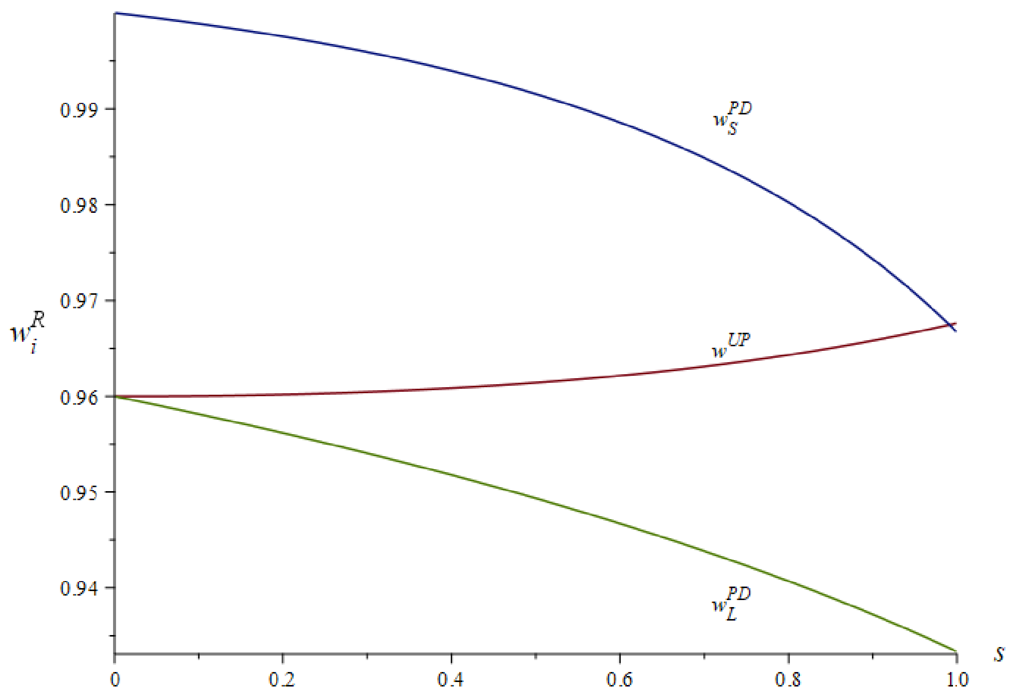

Figure 3.1: Wholesale prices.

also reduce the wholesale price to the small retailer. Hence, the wholesale prices are decreasing in s for both retailers under price discrimination. Uniform pricing, in contrast, removes the possibility of obtaining a competitive advantage, thereby reducing the large retailer's incentives to invest. Moreover, since the large retailer's investments make the rival (the small retailer) more aggressive—and more so the stronger the retail competition—the large retailer's investment incentives drop even further. The wholesale price is therefore increasing in s under uniform pricing.

For the large retailer, the gap in wholesale prices between uniform pricing and price discrimination increases in s. It is therefore obvious that price discrimination will benefit the large retailer. It also benefits consumers more as s increases, and is less profitable for the supplier. Further, the wholesale price towards the small retailer also decreases in s under price discrimination, but starts out at a higher level (the unconstrained $w^{NI} = 1$). By continuity, we still have the outcome that consumers are better off under uniform pricing, and that the supplier prefers price discrimination for s in the neighborhood of $s = 0$.

This begs for the question of whether there is a critical level of substitutability ($0 < s < 1$) such that consumers are better off with uniform pricing below this level, and the supplier is better off with uniform pricing above this level. A second question is whether consumers and suppliers always have opposing interests, or whether there could be an interval for s where supplier and consumer interests coincide.

We therefore propose the following:

Proposition 3.3 *There exist critical values $s_c \in (0,1)$ and $s_u \in (0,1)$, where $s_c \lesseqgtr s_u$, such that (i) the supplier prefers uniform pricing if $s \in (s_u, 1]$ and price discrimination if $s \in [0, s_u)$, (ii) the consumers prefer price discrimination if $s \in (s_c, 1]$ and uniform pricing if $s \in [0, s_c)$. The supplier and the consumers have conflicting interests if $s < min(s_c, s_u)$ or $s > max(s_c, s_u)$.*

Proof. See Appendix C.5. ■

The outcome when the retailers are sufficiently close substitutes, $s > max(s_c, s_u)$, resembles the result found by Akgün and Chioveanu (2019) and O'Brien (2014) under perfect substitutes. The supplier want to commit to uniform pricing through, e.g., wholesale MFN clauses, when there is strong competition between the retailers. At the same time, it follows from Corollary 3.1 that the supplier prefers price discrimination if the retailers are unrelated. The opposite is true for the consumers, however. Hence, at the extremes ($s = 0$ and $s = 1$), the consumers and the supplier have opposite interests, and the incentives move in opposite directions.

There may, however, be an intermediate interval of s where the supplier and consumer interests coincide. From Proposition 3.3, we have the following corollary:

Corollary 3.2 *If $s_c > s_u$, both the consumers and the supplier prefer uniform pricing in the interval $s \in (s_u, s_c)$, whereas if $s_c < s_u$, both the consumers and the supplier prefer price discrimination in the interval $s \in (s_c, s_u)$.*

The results in Proposition 3.3 and Corollary 3.2 are illustrated in Figure 3.2.[12] The substitutability parameter, s, is on the horizontal axis. The figure shows, on the vertical axis, the differences in supplier profits (red line) and consumer surplus (blue line), respectively, under uniform pricing and price discrimination ($u^{UP} - u^{PD}$ and $CS^{UP} - CS^{PD}$). The supplier or consumers prefer uniform pricing when the vertical axis shows positive values, whereas price discrimination is preferred for negative values.

In Figure 3.2, we can see that when the retailers are unrelated ($s = 0$), the supplier prefers price discrimination and the consumers prefer uniform pricing (Corollary 3.1). This is the case for $s \in [0, s_u)$. As the retailers are closer substitutes, the incentives of the supplier and consumers move in opposite directions. In the interval $s \in (s_u, s_c)$, both the supplier and the consumers are

[12] Figure 3.2 is constructed with parameter values in the region $c \in (\max\{\underline{c}, \overline{c}_S^{PD}\}, \overline{c}_L^{UP}]$ for all s ($\gamma = 8, c = 1.025$). That is, the small retailer never invests in equilibrium. See Appendix C.1 for derivations of supplier profit and consumer surplus.

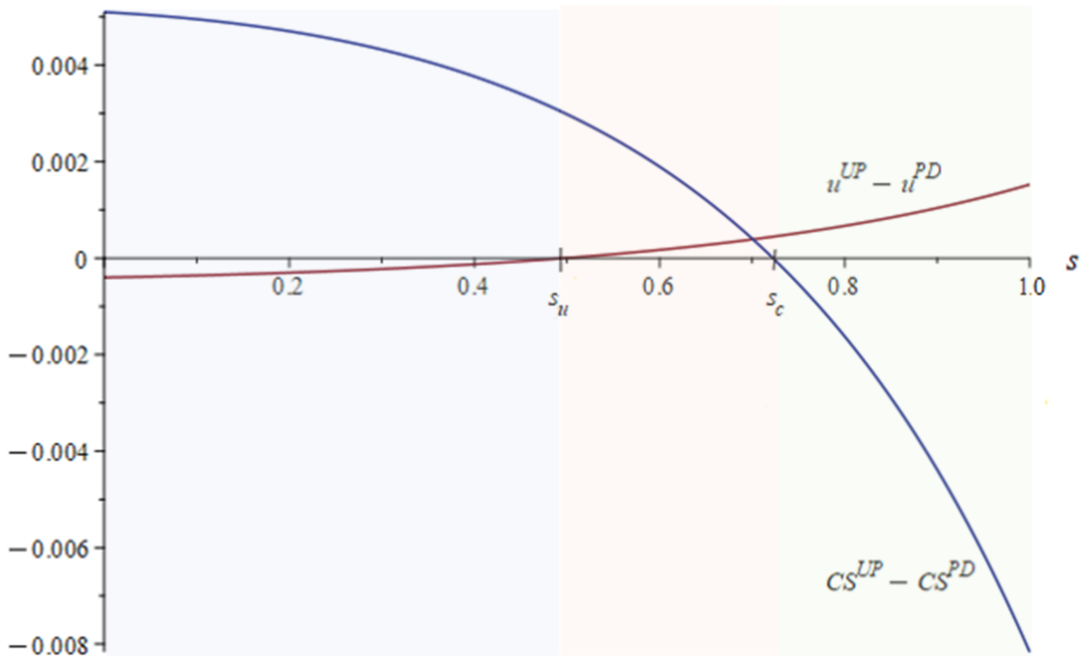

Figure 3.2: Consequences of uniform pricing on supplier profits and consumer surplus.

best off with uniform pricing.[13] However, as the retailers are closer substitutes—in the interval $s \in (s_c, 1]$—consumers will prefer price discrimination, whereas the supplier is better off with uniform pricing (Proposition 3.3). Who benefits from uniform pricing thus depends crucially on the degree of substitutability in the retail market.[14]

3.3 Extension: Inside options are binding for both retailers

Assumption 3.2 provides the sufficient conditions for when the large retailer invests and the small retailer does not invest under price discrimination. Let us now relax this assumption and consider the case where $c \in \left(\underline{c}, \bar{c}_S^{PD}\right)$, such that the inside option is binding for both retailers. Appendix C.3 solves the retailers' maximization problem, and presents the equilibrium outcomes. When the retailers are unrelated ($s = 0$), the small retailer will also invest, such that—contrary to the out-

[13]This is one potential outcome of Corollary 3.2. Under other parameter values, we cannot exclude the possibility that $s_c < s_u$, and we would have had the outcome that suppliers and consumers were all best off under price discrimination.

[14]The results on total welfare follow the same path as consumer surplus. However, we cannot provide any clear-cut results even at $s = 1$ as to whether uniform pricing or price discrimination yield the highest welfare. For details, see Appendix C.2.

come in the basic model—the small retailer obtains a lower wholesale price than the unconstrained wholesale price, although the price is nonetheless higher than the wholesale price the large retailer obtains. As in the case where the inside option is only binding for the large retailer, the uniform wholesale price is identical to the large retailer's price under price discrimination. The small retailer is therefore still better off with uniform pricing, $w_{L,s=0}^{PD-BI} = w_{s=0}^{UP} < w_{S,s=0}^{PD-BI} < w^{NI} = 1$. Both retailers' investment incentives increase with s under price discrimination.

In Appendix C.4, we derive the full condition for when the inside option is binding for the small retailer, and show that the small retailer will not invest if s is sufficiently large. This is because the small retailer is at this point better off free-riding on the large retailer's investments in inside options rather than making its own investments. The driving mechanism follows from Proposition 3.1: The closer rivals the retailers are, the more the supplier reduces the wholesale price to the small retailer. As a consequence, the closer substitutes are the retailers, the more profitable for the small retailer to not invest itself, but rather benefit from the lower price resulting from the large retailer's investments.

When $c \in \left(\underline{c}, \bar{c}_S^{PD}\right)$, the small retailer invests in the inside option. This only holds for sufficiently low values of s. As s becomes sufficiently large, such that $\max\{\underline{c}, \bar{c}_S^{PD}\} = \underline{c}$, the small retailer will no longer invest. We are then in the situation that $c \in (\underline{c}, \bar{c}_L^{UP}]$, where only the large retailer invests (as in the basic model). Since investment incentives are also lower for the large retailer when the small retailer does not invest, there is an upward shift in wholesale prices. This has consequences for supplier profit and consumer surplus as the small retailer goes from positive to no investments (i.e., when the inside option goes from binding to non-binding for the small retailer).

This case is depicted in Figure 3.3. To illustrate, we have set $\gamma = 4$ and $c = 1.025$. Figure 3.3 shows the differences in supplier profit and consumer surplus under each pricing regime. The inside option is a binding constraint for the small retailer in the interval $s \in [0, 0.252]$.[15] The supplier prefers to price discriminate, whereas the consumers are better off with uniform prices. For larger values of $s > 0.252$, the small retailer will not invest in equilibrium, and we obtain a picture similar to that in Figure 3.2, where the incentives eventually switch.

[15] By plotting for $\gamma = 4$ and $c = 1.025$ into the condition for when the inside option is binding for the small retailer (Equation (C.22) in Appendix C.4), and solving for s, we find that the small retailer will invest in the interval $s \in [0, 0.252]$.

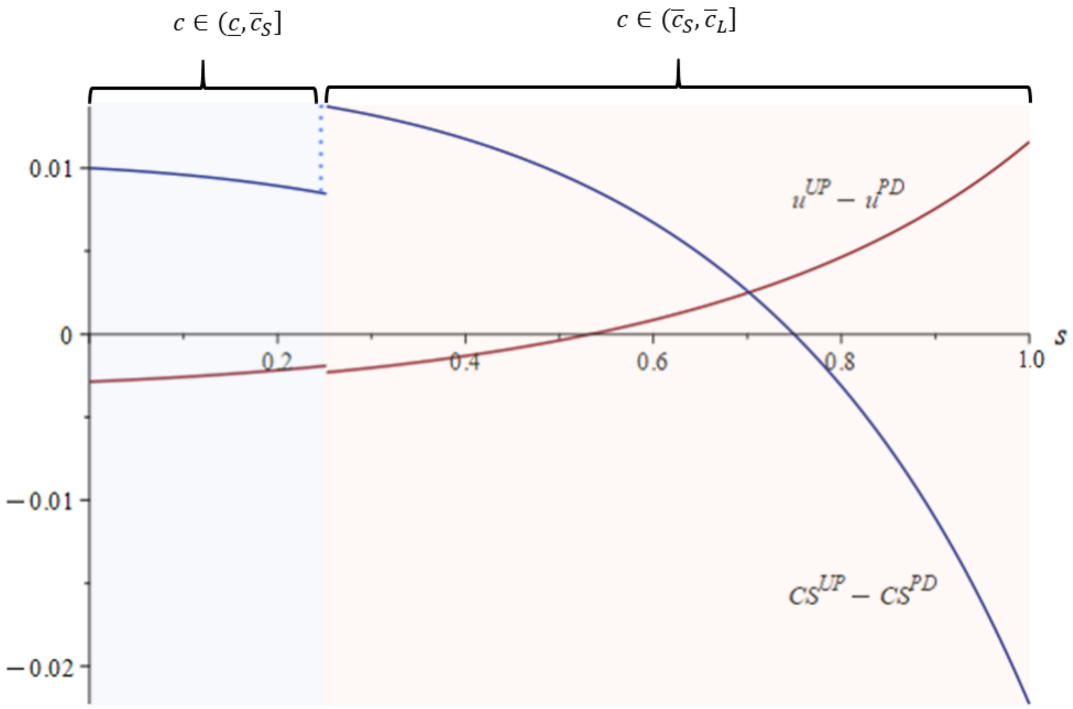

Figure 3.3: Consequences of uniform pricing on supplier profits and consumer surplus when S invests for sufficiently low s.

3.4 Concluding remarks

In this paper, we have shown how endogenous inside options may give rise to size-based wholesale price discrimination in favor of a large retailer, and that it is not clear-cut who benefits from uniform pricing and price discrimination, nor for which levels of substitutability among retailers. This stands in contrast to the clear-cut results given in the seminal papers by Katz (1987), O'Brien (2014), and Akgün and Chioveanu (2019). A large retailer clearly benefits from the supplier's ability to offer selective rebates, while smaller retailers are better off if the supplier is unable to price discriminate. More ambiguous is the effect on the supplier and the consumers, and we show that the degree of substitutability among the retailers is decisive. For low levels and high levels of substitutability, the supplier and the consumers have conflicting interests. However, for an intermediate level of substitutability, consumer and supplier interests can coincide.

The important distinction between inside and outside options is whether the investments take place before or after the supplier's decision on wholesale prices. This distinction may have a crucial impact on suppliers' incentives to price discriminate. In practice, however, retailers may improve their position towards suppliers through investments both ex ante negotiations with them, as well as through a credible threat of switching to an outside option ex post of the negotiations. Moreover, ex-ante investments may be necessary to create a credible threat of switching ex post. For example, in grocery retailing, where private labels can constitute an alternative source of supply, retailers will likely have to make significant investments prior to negotiations on wholesale prices with the brand suppliers for private labels to become a credible threat. If retailers decide to backward integrate and switch to a private label, they must likely undertake further investments.

In the book-publishing market, Amazon obtains low wholesale prices from suppliers (publishers) due to its size.[16] Gilbert (2015, p. 174) argues that an important part of Amazon's position is that it has a credible threat to backward integrate: "*Publishers have the additional concern that they will become an antiquated and redundant component of the book industry as Amazon increasingly deals directly with authors to supply books. Publishers fear that Amazon will 'disintermediate' the supply chain, replacing the traditional role of publishers to source and distribute content.*" This example illustrates that Amazon's credible threat comes from a combination of inside and outside options. Amazon undertakes investments into backward integration (Amazon Publishing), which provides proof of its ability to switch to an alternative source of supply.

In the multi-channel television market, a large player like Comcast, with its 23 million subscribers, has a size advantage over smaller rivals, such as Google Fiber and Cablevision, when it comes to using an alternative source of supply through backward integration into content programming. Doudchenko and Yurukoglu (2016) describe how Google Fiber emphasizes its significant disadvantage due to size-based wholesale price discrimination in favor of larger rivals such as Comcast. Also in this example, it seems reasonable that cable television providers need to make investments prior to negotiations on content wholesale prices in order to credibly threaten to—overnight—go to an alternative source of supply. Putting their threat into action would nonetheless involve further costs.

Finally, it is obviously a question of to what extent a supplier can commit to uniform pricing. In our model, a supplier that cannot commit to uniform pricing will provide a selective rebate to the large retailer. In several markets, we indeed observe that firms that control wholesale terms of trade may commit to non-discriminatory rules (e.g., wholesale MFNs). In other markets, we observe that firms are lobbying for non-discriminatory obligations, such as net-neutrality. As such, even if competition authorities do not actively pursue a non-discrimination policy, it is

[16] Gilbert (2015, p. 173) writes "*Amazon could seek to exploit its power as a large buyer to obtain low wholesale prices, rebates, or other concessions from its suppliers, and a credible concern is that Amazon will continue to press its suppliers for better terms. Publishers complain that at Amazon, today's wholesale price is the starting point for tomorrow's negotiations.*"

imaginable that the supplier could appeal to the competition law to signal that it is unable to price discriminate.

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Appendix C

C.1 Retailer profits, supplier profits, and consumer surplus

Stage 1 of the model is solved in Section 3.2.3. In this appendix, we demonstrate all results on retailer profits, supplier profits, and consumer surplus, under each price regime, uniform pricing (UP), and price discrimination (PD).

Uniform pricing: By inserting for w^{UP} from (3.13) into (3.9), we find the equilibrium quantities:

$$q^{UP} = \frac{\gamma(4-s)(2-c)}{\Omega}. \tag{C.1}$$

Recall that $\Omega = 8\left((\gamma - 1) + \gamma\left(1 - s\right)\right) + s\left(4 + s\gamma\right)$. Substituting for Equations (3.13) and (C.1) into Equations (3.10) and (3.11), net profit under uniform pricing for the small and the large retailers, respectively, become

$$\pi_S^{UP} = \frac{\gamma^2(2-s)(4-s)^2(2-c)^2}{\Omega^2} \tag{C.2}$$

and

$$\pi_L^{UP} = \frac{2\gamma(2-s)(2-c)^2}{\Omega^2}. \tag{C.3}$$

For the supplier, the profit in each local market is given by $u^{UP} = 2w^{UP}q^{UP}$. Consumer surplus follows from inserting q^{UP} into (3.6). Since both retailers have the same level of output, consumer surplus is $CS^{UP} = 2\left(q^{UP}\right)^2$. Hence, by inserting the wholesale prices from Equation (3.13) and quantities from Equation (C.1) into Equations (3.5) and (3.6), we can calculate the supplier's profits and the consumer surplus in each local market, respectively:

$$u^{UP} = \frac{2\gamma(4-s)(2-c)(\gamma(4-s)^2c - 8(2-s))}{\Omega^2} \tag{C.4}$$

and

$$CS^{UP} = \frac{2\gamma^2(4-s)^2(2-c)^2}{\Omega^2}. \tag{C.5}$$

Price discrimination: By inserting for w_S^{PD} and w_L^{PD} from (3.17) and (3.15), into (3.9), we find:

$$q_S^{PD} = \frac{1}{4-s} \text{ and } q_L^{PD} = \frac{\gamma(8-3s-(4-s)c)}{2(4-s)((2-s)\gamma-1)}, \tag{C.6}$$

such that by substituting Equations (3.15) and (C.6) into Equations (3.10) and (3.11), the net profit under price discrimination for the large and the small retailers, respectively, become

$$\pi_S^{PD} = \frac{2-s}{(4-s)^2} \tag{C.7}$$

and

$$\pi_L^{PD} = \frac{\gamma\left(4(2-c)-s(3-c)\right)^2}{2\left(4-s\right)^2\left((2-s)\gamma-1\right)}. \tag{C.8}$$

The supplier profit in each local market is $u^{PD} = w_S^{PD}q_S^{PD} + w_L^{PD}q_L^{PD}$. Consumer surplus follows from inserting q_S^{PD} and q_L^{PD} into (3.6). Hence, by inserting the wholesale prices from Equations (3.15) and (3.17), and the quantities from (C.6) into Equations (3.5) and (3.6), we can calculate the supplier's profits and the consumer surplus in each local market, respectively:

$$u^{PD} = \frac{8+(2-s)(4-s)\gamma\left[(4c(2-c)-(c+1)(3-c)s+4)\gamma-4(3-c)\right]}{2(4-s)^2((2-s)\gamma-1)^2} \tag{C.9}$$

and

$$\begin{aligned} CS^{PD} \quad &= \quad \frac{(2-s)[(s^2-32+80)\gamma^2+4-4\gamma(4-s)]-8\gamma s(3-s)}{8(4-s)^2((2-s)\gamma-1)^2} \\ &\quad + \frac{(4-s)[(2-s)[c^2\gamma^2(4-s)-2c\gamma^2(8-s)]+4c\gamma s]}{8(4-s)^2((2-s)\gamma-1)^2}. \end{aligned} \tag{C.10}$$

C.2 Total welfare

Total welfare in each local market is the sum of the retailers' profits, consumer surplus, and the supplier's profits in each local market. Note that Equations (C.3) and (C.8) represent the net profit for the large retailer under uniform pricing and price discrimination, respectively. The large retailer is present in two local markets. We therefore divide net profit by two to find the per-outlet profits for L.

Uniform pricing: Using (C.2), (C.3), (C.4), and (C.5), total welfare under uniform pricing is hence

$$W^{UP} = 2\gamma(2-c)\left[\frac{\gamma(4-s)^2(c+2(3-s))+2c(2-s)^2+4s(16-3s)-80}{\Omega^2}\right]. \tag{C.11}$$

Price discrimination: Using (C.7), (C.8), (C.9), and (C.10), total welfare under price discrimination is hence

$$W^{PD} = (4-s)c\gamma\Big[\frac{8(8-3s)-2c(4-s)-(2-s)\gamma((4-s)c+2(8-3s))}{8(4-s)^2((2-s)\gamma-1)^2}\Big] + \frac{(39s^2-224s+304((2-s)\gamma^2-2\gamma)-12s+56}{8(4-s)^2((2-s)\gamma-1)^2}. \tag{C.12}$$

Figure C.1 illustrates (for $\gamma = 8, c = 1.025$) that the difference in total welfare under each price regime ($W^{UP} - W^{PD}$) follows the same path as the difference in consumer surplus.

For $s = 0$, total welfare is highest under uniform pricing. Only the supplier prefers price discrimination. As s increases, price discrimination becomes more attractive from a total welfare perspective. We have been able to deliver clear-cut results on which regime is preferred for supplier profits and consumer surplus when $s = 1$ (see Proposition 3.3). This cannot be done for total welfare, however. In Figure C.1, constructed with the parameter values $\gamma = 8$ and $c = 1.025$, total welfare is highest under price discrimination at $s = 1$. This is not a general result. For other parameter values, uniform pricing might yield higher total welfare since investment competition becomes so tough when s is large that the investments might become too costly. As such, price discrimination might become socially harmful.

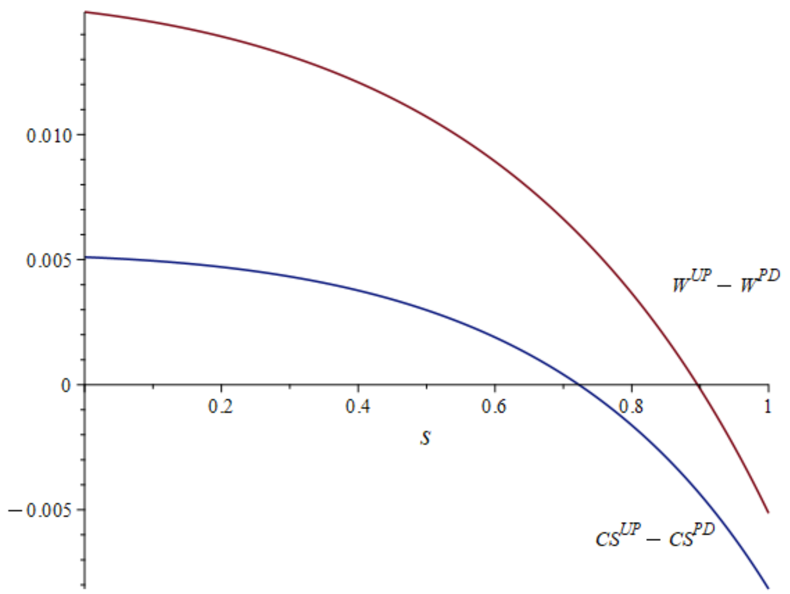

Figure C.1: Differences in total welfare follow differences in consumer surplus.

C.3 Inside option is binding for both retailers

We now assume that $\underline{c} < c < \overline{c}_S^{PD} < \overline{c}_L^{UP}$, such that both retailers invest (BI). The net profits for the small and large retailers, respectively, are given by Equations (3.10) and (3.11), where the cost of investment is given by (3.4). Each retailer i solves

$$\max_{x_i^{PD-BI}} \pi_i^{PD-BI} \text{ s.t. } w_i^{PD-BI} = c - x_i^{PD-BI},$$

which yield the retailers' response functions:[17]

$$x_S^{PD-BI}(x_L^{PD-BI}) = \frac{4\,(2-s)^2}{\gamma\,(4-s)^2\,(4-3s)^2 - 8\,(2-s)^3}\left[(2-c)\,(4-3s) - s x_L^{PD-BI}\right]$$

and

$$x_L^{PD-BI}(x_S^{PD-BI}) = \frac{8\,(2-s)^2}{\gamma\,(4-s)^2\,(4-3s)^2 - 16\,(2-s)^3}\left[(2-c)\,(4-3s) - s x_S^{PD-BI}\right].$$

We observe that the investments are strategic substitutes ($dx_i(x_j)/dx_j < 0$).

By solving the reaction functions simultaneously, we obtain the investments by the small and large retailers, respectively, as given by

$$x_S^{PD-BI} = \frac{2-c}{4\gamma-1} + s\frac{(2-c)\gamma(4-s)(3s^2-12s+16)(4-3s)^2\gamma - 4(9s^2-40+48)(2-s)^2}{(4\gamma-1)\Theta} \tag{C.13}$$

and

$$x_L^{PD-BI} = \frac{2-c}{2\gamma-1} + s\frac{(2-c)\gamma(4-s)(3s^2-12s+16)(4-3s)^2\gamma - 16s(2-s)^2}{(2\gamma-1)\Theta}, \tag{C.14}$$

where $\Theta = (4-s)^3(4-3s)^3\gamma^2 - 24\gamma(4-s)(4-3s)(2-s)^3 + 32(2-s)^4$.

As in the case where the inside option is only binding for the large retailer, the investment level of the large retailer is identical under uniform pricing and price discrimination if $s = 0$ (the first term in Equation (3.13) is identical to (C.14) evaluated at $s = 0$), also when the inside option is binding for both retailers. From Equations (3.13) and (C.14), we have

$$x_L^{PD-BI} > x_L^{UP} \implies w_L^{PD-BI} < w^{UP} \text{ if } s > 0.$$

[17]Stability requires $|dx_L(x_S)/dx_S| < 1$. Since the best-response functions increase in s, the stability restriction is strictest at $s = 1$. Therefore, $|dx_L(x_S)/dx_S|_{s=1} = \frac{8}{9\gamma-16} < 1$ if $\gamma > \frac{8}{3}$ (Assumption 3.3).

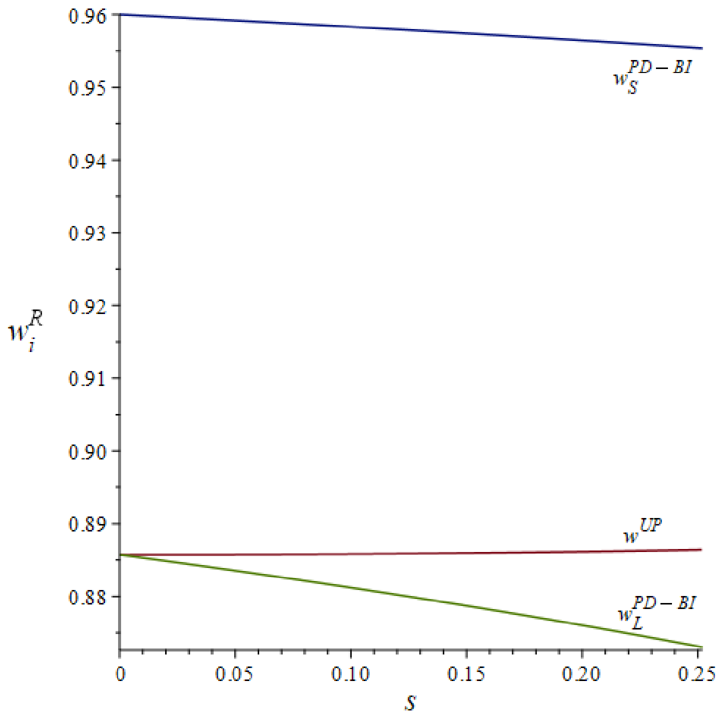

Figure C.2: Wholesale prices when the inside option is binding for both retailers.

The wholesale price offered to the small retailer, however, is now lower than the unconstrained wholesale price, such that $w_S^{PD-BI} < w^{NI}$, when $s = 0$ (compare the first firm in Equations (3.13) and (C.13)). Since x_S^{PD-BI} increases in s, w_S^{PD-BI} is decreasing in s:

$$\frac{\partial x_S^{PD-BI}}{\partial s} > 0 \to \frac{\partial w_S^{PD-BI}}{\partial s} < 0.$$

Note also that the small retailer invests less than the large retailer in either price regime, and from Equations (3.13) and (C.13), we therefore have:

$$x_S^{PD-BI} < x_L^{UP} \implies w_S^{PD-BI} > w^{UP}.$$

Figure C.2 illustrates how the wholesale prices move when the inside option is binding for both retailers. The figure is illustrated with $\gamma = 4$ and $c = 1.025$ (as in Section 3.3; the inside option is therefore only binding in the region $s \in [0, 0.252]$).

By inserting the investments from (C.13) and (C.14) into the stage-three equilibrium quantities in (3.9), we obtain the following equilibrium outputs:

$$q_S^{PD-BI} = \frac{(4-s)(4-3s)(2-c)\gamma((4-s)(4-3s)^2\gamma - 8(2-s)^2)}{\Theta} \tag{C.15}$$

and

$$q_L^{PD-BI} = \frac{(4-s)(4-3s)(2-c)\gamma((4-s)(4-3s)^2\gamma - 4(2-s)^2)}{\Theta}. \tag{C.16}$$

Inserting the quantities from Equations (C.15) and (C.16) into (3.10) and (3.11), the net profits for the small and large retailer, respectively, are

$$\pi_S^{PD-BI} = \frac{\gamma(2-c)^2(2-s)((4-s)^2(4-3s)^2\gamma-8(2-s)^3)((4-s)(4-3s)^2\gamma-8(2-s)^2)^2}{\Theta^2} \tag{C.17}$$

and

$$\pi_L^{PD-BI} = \frac{2(2-c)^2(2-s)((4-s)^2(4-3s)^2\gamma-16(2-s)^3)((4-s)(4-3s)^2\gamma-4(2-s)^2)^2}{\Theta^2}. \tag{C.18}$$

By inserting the quantities from Equations (C.15) and (C.16) into (3.6) and (3.5), we can calculate the supplier's profits and the consumer surplus in each local market, respectively:

$$u^{PD-BI} = \frac{2\gamma(4-s)(4-3s)(2-c)\left[\Lambda\right]}{\Theta^2}, \tag{C.19}$$

where $\Lambda = c\gamma^3(4-s)^4(4-3s)^5 + 128\gamma(4-s)(4-3s)^2(2-s)^4 + 16c\gamma(10-3s)(4-3s)(4-s)(2-s)^4 - 12\gamma^2(2-s)^2(4-s)^2(4-3s)^3\left[c(4-s)+(4-3s)\right] - 384(2-s)^6$,

and

$$CS^{PD-BI} = \frac{2\gamma(4-s)^2(4-3s)^2(2-c)^2\left[\Upsilon\right]}{\Theta^2}, \tag{C.20}$$

where $\Upsilon = \left[(4-s)^2(4-3s)^4\gamma^2 + 4(10-s)(2-s)^4 - 12\gamma(4-s)(4-3s)^2(2-s)^2\right]$.

C.4 Conditions for binding inside options

The large retailer

The inside option is binding for the large retailer under uniform pricing as long as $\pi_L^{UP} - \pi_L^{NI} \geq 0$, where π_L^{UP} (Equation (C.3)) is the profit for the large retailer under uniform pricing if the inside option is binding, and $\pi_L^{NI} = 2\left(2-s\right)\left(q^{NI}\right)^2$ is the profit if the inside option is not binding, where q^{NI} is given by (3.7). We find that $\pi_L^{UP} - \pi_L^{NI} \geq 0$ if

$$c \leq \bar{c}_L^{UP}(s) = 2 - \frac{\sqrt{\gamma\Omega}}{\gamma\left(4-s\right)}. \tag{C.21}$$

Since the large retailer has lower investment incentives under uniform pricing compared to under price discrimination, the condition above ensures that the large retailer invests under both regimes. Furthermore, under uniform pricing, the large retailer's investment decreases in s. A sufficient condition to ensure that the large retailer invests is thus to insert for $s = 1$, which is given by Assumption 3.2.

The constraint in Equation (C.21) is illustrated in panel (a) of Figure C.3. The large retailer will invest in the area below the graph, and is restricted downwards by $c > \underline{c} = 1$.

The small retailer

The inside option is never binding for the small retailer under price discrimination as long as $\pi_S^{PD} - \pi_S^{PD-BI} \geq 0$, where π_S^{PD} is the profit for the small retailer if the inside option is not binding and is given by (C.7), and π_S^{PD-BI} is the profit if the inside option is binding for the small retailer and is given by (C.17), such that both retailers invest. We find that $\pi_S^{PD} - \pi_S^{PD-BI} \geq 0$ if

$$c \geq \bar{c}_S^{PD} = 2 - \sqrt{\frac{\left[(4-s)^3(4-3s)^3\gamma^2 - 24\gamma(4-s)(4-3s)(2-s)^3 + 32(2-s)^4\right]^2}{(4-s)^2\gamma\left[(4-s)^2(4-3s)^2\gamma - 8(2-s)^3\right]\left[(4-s)(4-3s)^2\gamma - 8(2-s)^2\right]^2}}. \tag{C.22}$$

The small retailer will not invest under uniform pricing, and instead free-ride on the large retailer's investments. Therefore, the inside option is never binding for the small retailer under uniform pricing. Since $\bar{c}_S^{PD}$ decreases in s (see panel (b) of Figure C.3), a sufficient condition to ensure that the small retailer does not invest is that $c \geq \max\left\{\underline{c}, \bar{c}_S^{PD}\right\}$ for $s = 0$, which is given by Assumption 3.2.

Another implication from Equation (C.22) is that the small retailer will only invest if $c \in (\underline{c}, \bar{c}_S^{PD}]$. This is the case for $s = 0$ and holds if s is sufficiently low. However, the small retailer will never invest in the inside option if s is sufficiently high. The constraint in Equation (C.22) is illustrated in panel (b) of Figure C.3. S will invest in the area below the graph, and is restricted downwards by $c > \underline{c} = 1$. From the figure, it becomes clear that the small retailer will only invest in the inside option if s is sufficiently low.

C.5 Proof Proposition 3.3

Using Equations (C.4) and (C.9), evaluated at $s = 1$, we find the following difference in supplier profits under each pricing regime:

$$\begin{aligned}(u^{UP} - u^{PD})|_{s=1} \quad = \quad & \frac{-243(c-1)^2\gamma^4 + 108(12c-13)(c-1)\gamma^3}{18(9\gamma-4)^2(\gamma-1)^2} \\ & + \frac{(168 - 36c(23c-22))\gamma^2 + (672c-576)\gamma - 128}{18(9\gamma-4)^2(\gamma-1)^2},\end{aligned}$$

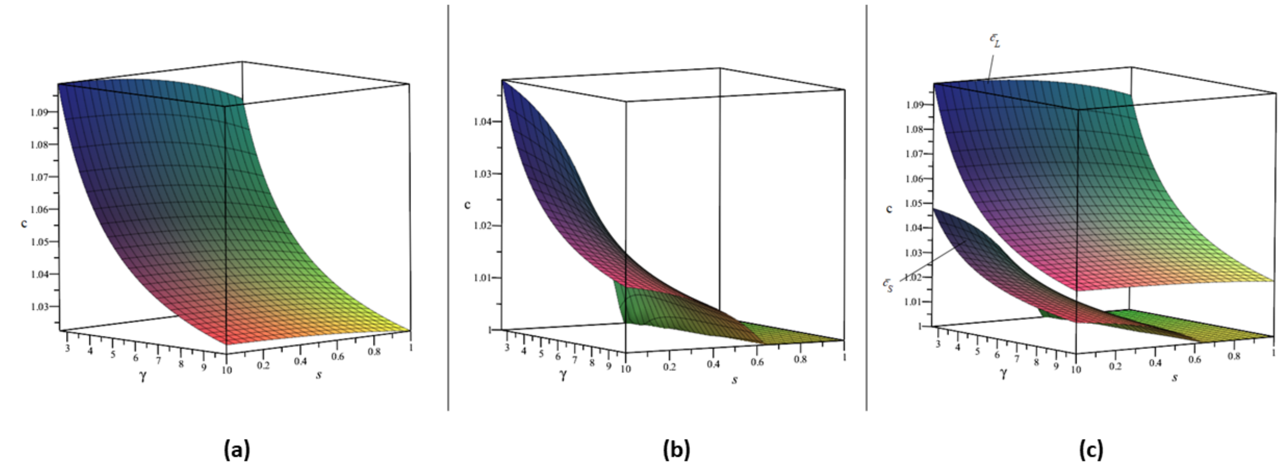

*Figure C.3: Constraints on c when the inside options are binding. Panel **(a)** displays $\overline{c}_L^{UP}$ (the constraint for when the inside option is binding for retailer L, cf. Equation (C.21)), panel **(b)** displays $\overline{c}_S^{PD}$ (the constraint for when the inside option is binding for retailer S, cf. Equation (C.22)), and panel **(c)** displays both constraints in the same diagram. L invests whenever the parameter values of γ, s, and c are below the plane in **(a)**, while S invests whenever the parameter values of γ, s, and c are below the plane in **(b)**.*

which is positive for all $\gamma \in \left(\frac{8}{3}, \infty\right)$ in the relevant region $c \in (\underline{c}, \overline{c}_L]$.[18] That is, the supplier prefers uniform pricing at $s = 1$.

Using Equations (C.5) and (C.10), evaluated at $s = 1$, we find the following difference in consumer surplus under each pricing regime:

$$(CS^{UP} - CS^{PD})|_{s=1} = \frac{\left[9(c-1)\gamma^2 + (26-24c)\gamma + 8\right]\left[-(135-63c)\gamma^2 + (118-48c)\gamma - 8\right]}{72(9\gamma-4)^2(\gamma-1)^2},$$

which is negative for all $\gamma \in \left(\frac{8}{3}, \infty\right)$ in the relevant region $c \in (\underline{c}, \overline{c}_L]$.[19] Hence, consumers prefer price discrimination at $s = 1$.

From Corollary 3.1, we know that consumers are better off under uniform pricing, while the supplier is better off with price discrimination when retailers are unrelated ($s = 0$). Thus, by continuity, Proposition 3.3 follows. ■

[18] To see this, let us first consider $\gamma \to 8/3$. Evaluating Equation (C.21) for $\gamma \to 8/3$ yields $\overline{c}_L \to 1.0871$, and $u^{UP} - u^{PD} \to 0.2784 > 0$. If $\gamma \to \infty$, then $\overline{c}_L \to 1$, and $u^{UP} - u^{PD} = \frac{132\gamma^2+96\gamma-128}{18(9\gamma-4)^2(\gamma-1)^2} > 0$.

[19] To see this, let us first consider $\gamma \to 8/3$. Evaluating equation (C.21) for $\gamma \to 8/3$ yields $\overline{c}_L \to 1.0871$, and $CS^{UP} - CS^{PD} \to -0.050908 < 0$. If $\gamma \to \infty$, then $\overline{c}_L \to 1$, and $CS^{UP} - CS^{PD} = \frac{[2\gamma+8][-72\gamma^2+70\gamma-8]}{72(9\gamma-4)^2(\gamma-1)^2} < 0$ (the second square bracket in the numerator is clearly negative).

Chapter 4

Classroom experiments on technology licensing: Royalty stacking, cross-licensing, and patent pools

Chapter 4

Classroom experiments on technology licensing: Royalty stacking, cross-licensing, and patent pools*

Atle Haugen and Steffen Juranek

NHH Norwegian School of Economics

Abstract

The authors present two classroom experiments on technology licensing. The first classroom experiment introduces the concept of royalty stacking. Students learn that non-cooperative pricing of royalties for complementary intellectual property rights leads to a double-marginalization effect. Cooperation solves the problem and is welfare-improving. The second classroom experiment introduces students to cross-licensing. It shows that reciprocal royalty payments dampen competition. The classroom experiments stimulate discussions of technology licensing, intellectual property rights, different royalty structures, patent pools and technology standards. The authors present the experimental procedures, and suggests routes for the discussion.

Keywords: Classroom experiment, cross-licensing, licensing, patent pools, royalty stacking.
JEL classification: A2, L24, O3.

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Contact: Department of Economics, NHH Norwegian School of Economics, atle.haugen@nhh.no and Department of Business and Management Science, NHH Norwegian School of Economics, steffen.juranek@nhh.no.

4.1 Introduction

As technology is on the rise in today's business world, intellectual property rights (IPRs) become increasingly important. This is illustrated by the development of the number of granted patents over time. With more than 350,000 patents, the United States Patent and Trademark Office (USPTO) granted in 2020 more than twice as many patents than a decade earlier.[1] A similar development can be observed at the European Patent Office (EPO).[2] However, technologies protected by patents are not only used by the patent owners but also by others. Hence, the increasing importance of patents, and intellectual property rights in general, also increases the importance of licensing. The International Monetary Fund (IMF) reports that licensing payments for cross-country transactions alone amount to more than $440 billion in 2019, an increase of more than 80 percent over the previous 10 years.[3] In light of the growing importance of licensing, we contribute with an engaging teaching method on the topic by presenting two classroom experiments.

The aim of the classroom experiments is threefold: First, students learn about specific concepts—royalty stacking, cross-licensing and patent pools—by taking the roles of decision makers. The aim is to understand the concepts but also the implications for corporate strategy and regulation. Second, the classroom experiments require students to participate actively during a lecture and motivate students to participate in the discussion. Thereby, the classroom experiments contribute to maintaining an engaging learning environment. Third, the classroom experiments relate to other concepts within licensing and intellectual property rights and, therefore, contribute to the learning of those concepts as well.

The first classroom experiment discusses royalty stacking (see, e.g., Shapiro 2000). In the classroom experiment, students learn about a specific problem related to licensing of complementary technologies, and how it can be solved. Royalty stacking emerges when producers require access to technologies protected by multiple patents (or other intellectual property rights) that are owned by different entities. With dispersed ownership, the total royalty for access to all patents is higher compared to a situation where the ownership of the required patents is concentrated. The problem of royalty stacking is essentially a problem of pricing complements, dating back to Cournot (1838). It is a variant of the double (multiple) marginalization problem (see, e.g., Tirole 1988).[4]

[1]Source: https://www.uspto.gov/web/offices/ac/ido/oeip/taf/us_stat.htm.

[2]Source: PATSTAT, Spring 2021.

[3]Source: International Monetary Fund, Balance of Payments Statistics Yearbook and data files – "Charges for the use of intellectual property, payments (BoP, current US$)". https://data.worldbank.org /indicator/BM.GSR.ROYL.CD

[4]Double marginalization occurs when two entities offer complementary goods or services. As the two

Patents protect technologies rather than necessarily directly products. As many products actually combine multiple technologies, a producer often requires access to multiple patents. This is quite natural to occur as inventors stand on the shoulders of giants and often apply previous inventions to reach new discoveries. For example, according to a US government report, a typical smartphone uses from 50,000 to 250,000 patented technologies (GAO 2013). Similar observations can be made for other products in the information technology sector (Lemley and Shapiro 2007). Moreover, even for one specific technology, technology standards can rely on several hundred patents (Rysman and Simcoe 2008).

Similar to the standard double-marginalization problem, royalty stacking occurs because each patent owner does not take into account the effect of its royalty choice on other patent owners. The resulting problem is not only welfare-decreasing but leads to an inferior outcome for everyone involved: IPR owners, producers, and consumers. One way to solve the problem is to create a patent pool that sets only one royalty for access to the essential patents (e.g., Lerner and Tirole 2004). At this point, the second classroom experiment enters the picture. The second experiment is about cross-licensing. Cross-licensing is a common practice in a variety of industries as shown by Taylor and Silberston (1973) already five decades ago. Through the rising numbers of patent rights, its prominence increased as illustrated by its use in the smartphone and semiconductor industry (see, e.g., Grindley and Teece 1997). Understanding cross-licensing is therefore essential for anyone working on or with technology licensing. Cross-licensing is also a particular feature of patent pools. This experiment illustrates that when two competitors require access to each other's patents, a reciprocal royalty can be used to dampen competition between them.

Both experiments can be embedded well in a discussion on licensing from a business perspective. They can also be applied for an antitrust discussion on licensing. The first experiment shows that coordination with owners of complementary IPRs can be beneficial in order to decrease transaction costs. As licensing is a market transaction, it causes direct transaction costs in the form of contracting costs. However, the experiment shows that there can also be other transaction costs. If complementary IPRs are owned by different owners, the IPR owners aim to maximize their own profit and disregard the effect of their decision on the others. As the experiment shows, that leads to higher royalty rates for the licensee. Moreover, decreasing transaction costs is not only individually beneficial but also positive for welfare. Hence, from an antitrust perspective, coordination, e.g., by forming patent pools, is considered in principle positively. The second experiment then shows that if the owners of complementary IPRs are also competitors,

entities maximize only their own profit, they ignore the negative effect of their price choice on the other entity. As a result, the two entities set too high prices to maximize joint profits.

the access to these assets affects the competitive situation. This is obviously important from a business perspective but is likely to be harmful for consumers and should, hence, be scrutinized by competition authorities.

The experiments can also be used to discuss different kinds of royalties, i.e., per-unit, ad valorem or fixed payments. In principle, both problems presented by the experiments would vanish at the margin with a fixed payment. This observation is a good starting point to make the students think about the benefits and costs of variable royalties. Furthermore, we use the experiments to motivate discussions on patent pools, patent thickets, technology standards and standard-essential patents.

The target courses for the experiments are innovation courses for business and economics students but also courses on competition policy for business, economics and law students. The feedback of our students has shown that the classroom experiments contribute to an engaging learning environment and facilitates discussions among the students. Our experience is in line with the empirical investigation of classroom experiments. Frank (1997), Emerson and Taylor (2004), Durham et al. (2007) and Emerson and English (2016) all provide evidence of positive and significant learning gains from classroom experiments on the learning of economics.

4.1.1 Background

Key concepts

Technology licensing: A license can be granted in a multitude of cases. Licenses are for example granted for real property, software, artwork, or brands. Our classroom experiments focus on licensing of technology, typically covered by patents. By licensing a patent, the licensee has the right to use the protected technology within the scope of the agreement. A license can be exclusive – worldwide or within a specific territory – or non-exclusive and may require restrictions on how the technology can be used by the licensee. There are at least two reasons for a company to license a patent (see, e.g., Scotchmer 2005, Ch. 6). First, production efficiency. Someone else may have an advantage in producing the protected technology. That includes advantages in distribution and efficient targeting of customers (e.g., geographically). Second, to let others use the technology as an input. That can include competitors but also producers of completely unrelated products. Licensing of patents has long been common practice. For example, based on the PatVal-EU survey data, Gambardella et al. (2007) report that 11.4 percent of the respondent's patents were licensed out.

Cross-licensing: In a cross-licensing agreement at least two firms grant each other access to their patents. Such agreement may or may not involve fixed fees or per-unit/ad valorem royalties (Shapiro 2000). Similar to a common licensing agreement, a cross-licensing agreement can be exclusive and contain other restrictions. Famous examples can be found in the smartphone sector. The sector is characterized by a large number of intellectual property rights that are required for production. As these are owned by the different producers, cross-licensing can be helpful.[5] For example, Samsung and Google entered a cross-licensing agreement,[6] Apple and HTC entered one,[7] and Apple and Microsoft signed another one.[8] The list could be extended within the sector but also to other industries.

Patent pools: In a patent pool, a group of patents is licensed in a package (Shapiro 2000). The members of the patent pool license their patents to each other and/or to third parties. The pool then shares the licensing revenues among the pool members, typically in proportion to each patent's value (WIPO 2014). Patent pools are common for more than a hundred years. Early examples are the Manufacturer's Aircraft Association formed in 1914, or the Radio Corporation of America pool formed in 1920. More recent examples are the mp3, BluRay or MPEG4 technologies (see Baron and Pohlmann 2015, for an overview of examples within the Information and Communication Technology). As these examples show, patent pools are commonly related to a technological standard and aim to collect the standard essential patents.

Patent pools have the advantage of decreasing transaction costs. That includes explicit costs such as costs of negotiating and contracting but also implicit transaction costs such as royalty stacking – the center of the first classroom experiment. A problem is, however, the potential anti-competitive use of patent pools. As we will see, royalty stacking occurs only for complementary patents. Avoiding royalty stacking benefits the producers and the consumers and is therefore welfare beneficial. In contrast, joint price-setting of substitutes benefits only producers but harms consumers through higher prices. Because patent owners have also an incentive to include substitute patents into a pool, a pool can become anticompetitive.

Patent thickets: A common expression in innovation economics is that we are "standing on the shoulder of giants", i.e., that new innovations build on previous innovation – innovation is

[5]There is also significant disagreement on the coverage of certain patents as the sector is also known for its large number of patent lawsuits (see, e.g., *Forbes*, March 13, 2020, "Samsung vs. Apple: Inside The Brutal War For Smartphone Dominance", https://www.forbes.com/sites/forbesdigitalcovers/2020/03/13/samsung-vs-apple-inside-the-brutal-war-for-smartphone-dominance/).

[6]See the New York Times, January 27, 2014, "Google and Samsung Sign Broad Cross-Licensing Agreement", https://www.nytimes.com/2014/01/28/technology/google-and-samsung-sign-broad-cross-licensing-agreement.html.

[7]The Wallstreet Journal, November 11, 2012, "Apple, HTC Settle Patent Dispute, Sign Licensing Pact", https://www.wsj.com/articles/SB10001424127887324894104578111792346747174.

[8]The Wallstreet Journal, September 29, 2011, "Microsoft-Samsung Deal Strikes a Blow at Google", https://www.wsj.com/articles/SB10001424052970204226204576598661866214854.

cumulative (Scotchmer 2005). The mRNA vaccine that reached a very prominent status during the Covid-19 pandemic is an example for this. The idea of an mRNA vaccine is more general than its application on Covid-19 but it required nonetheless extensive additional research for the specific case. In general, even very simple products often combine multiple technologies. For example, standard car tires combine the idea of an air-filled tire with the technology of vulcanized rubber. The consequence of cumulative innovation is that the more a technological field develops, the more technologies are combined. This makes it more and more difficult to identify all relevant intellectual property rights, i.e., a patent thicket is created. In the words of Shapiro (2000), a patent thicket is defined as "a dense web of overlapping intellectual property rights that a company must hack its way through in order to actually commercialize new technology." Specifically, in environments with patent thickets, patent pools may be of help in order to decrease the level of uncertainty.

Prerequisites

We have implemented the experiments only in Master level courses, but we do not see any obvious hurdles of implementing them in final year Bachelor courses. In order to achieve a valuable outcome of the experiments, the students need to be aware of certain concepts. First, students should be introduced to intellectual property rights; in particular, of patents. The third chapter of Scotchmer (2005) offers an excellent introduction to the topic. In order to complement this with specific cases, the European Patent Office offers a valuable resource with its "IP Teaching Kit". However, because the teaching kit is quite extensive, we recommend using the content selectively. Second, the class should have been introduced to licensing in general and different royalty structures (fixed fee, per unit and ad valorem royalties) in particular. Topics that can be discussed here are production distortion due to variable royalties as they increase the marginal costs of the licensee, and risk-sharing considerations of fixed vs variable royalty payments. Third, the students should have attended standard introductory classes in microeconomics. This background is helpful because students then do not only have a basic understanding of strategic interaction but also of competition policy. Finally, an understanding of game theory is helpful but not strictly required.

4.1.2 Related classroom experiments

Our two experiments contribute to the literature on classroom experiments on intellectual property rights. Whereas there exists an extensive list over the literature on classroom experiments in the economics field (see, e.g., Picault 2019), only few experiments cover patents and technology licensing. Bernard and Yiannaka (2010) offer an experiment on the patenting decision, in which the students determine whether to file for a patent or keep the innovation a trade secret. Further, the experiment allows for discussions on the implications of broad versus narrow patents. Diduch (2010) provides an experiment on R&D competition, in which students determine research effort in response to two different incentive structures: a 'winner-take-all' system and one in which there are extensive knowledge externalities. The experiment illustrates how a 'winner-take-all' system can lead to over-investments, whereas knowledge spillovers lead to a free-riding problem and under-investments. Finally, Picault (2020) suggests an innovative experiment design on the incentives to invest in technology when the technology is patented versus open-source technology.

For instructors of an innovation course, our experiments are natural successors of the experiments of Bernard and Yiannaka (2010) and Diduch (2010). Whereas those experiments concentrate on the process to filing for patent, our experiments take it one step further, and discuss private consideration as well as welfare and antitrust concerns when innovators build on previous innovations and share patents. We are not aware of any other experiments on the licensing of patents.

For instructors of more general industrial organization courses, our experiments highlight the relevance of licensing for firm strategy and competition policy and can follow on experiments on duopoly competition and collusion (e.g., Beckman 2003; Picault 2015).

4.2 Royalty stacking

4.2.1 Learning goals

1. Understanding the strategic interaction between owners of complementary technologies and the problem of royalty stacking.

2. Knowledge on the concept of patent pools and how patent pools can solve the royalty stacking problem.

3. Understanding differences in the pricing of complements and substitutes.

4. Learning about strategic interaction and game-theoretical considerations.

4.2.2 Procedure

The experiment takes around 60 minutes including discussions. The instructions and a list of required material can be found in the Appendix. In the experiment, a student takes the role of a patent owner that sets a royalty for access to its patent from a manufacturer. The manufacturer requires access to two patents in order to sell its product. Hence, two patent owners, i.e., students, form a pair. The manufacturer itself is passive. Its production depends on the sum of the royalties. We use a simple linear demand function $q = 12 - r_1 - r_2$, where r_i is the royalty of patent owner i in € (or another currency).[9] Each patent owner maximizes its individual profit, which is given by $\pi_i = r_i q$.

We start by distributing the instructions (see the Appendix D.2).[10] The students are asked to read them carefully. Then, in order to match two patent owners, we recommend to print numbered record sheets. In order to assign students a unique ID, we bring an "A" and a "B" version of the numbers such that A1 is matched to B1. We usually distribute the record sheets among the students such that a pair sits relatively far away from one another. This impedes communication in the non-cooperative rounds, and has the side effect that students mingle and get to know each other in the cooperative round. We performed the experiment with up to 80 students, i.e., 40 groups.[11] For even larger classes one may consider forming groups representing one decision maker.

We experienced that it is beneficial to either write the demand schedule on the blackboard or use the projector for it. After the students are done reading, it is important to explain the procedure once more and to clarify questions. We ask the students to write down their decision on the record sheet. After each round, they submit their decision, and we record the decisions in a prepared spreadsheet.

The experiment consists of two phases: the non-cooperative and cooperative phase. We usually run two rounds of the non-cooperative phase as described in the instructions. The first round is then kind of a practice round, as it helps the students to understand the set-up. A second round of the non-cooperative set-up can also be interesting, because the behavior of the students often shows some dynamics as students quickly realize the interdependence of the decisions. A

[9]Badasyan et al. (2009) present a classroom experiment on double marginalization along the supply chain and how it can be solved by vertical integration. Beckman (2003) proposes a classroom experiment on Cournot and Bertrand Games and includes the case of perfect complements. Both articles use the same simple demand function.

[10]In our main description, we focus on an execution in the classroom. In the end of this document, we provide some input for online settings.

[11]We implemented it five times in courses on innovation management. We performed it four times with 14–30 students, and once with around 80 students.

third round is only necessary if the students were struggling to understand the set-up. Students usually require around 10–15 minutes to answer the first round, and around five minutes in the second (and third) round.

In the second phase, the pair of patent owners cooperate and set a joint royalty that is equally split. The patent owners are asked to sit together and to determine the joint royalty. We did not give extra incentives to the students. The reason is that our institutions restricts us giving extra credits. However, incentivizing the students may even improve the engagement of the students.

4.2.3 Discussion

We usually do not strictly differentiate between the procedure and discussion. After each round, we ask students for their considerations. In particular, we challenge the students who chose the "cooperative" royalty of 3€ for the reasoning behind their decision. That will often already lead to some discussion. In case it does not, we ask a student with a higher price for their reasoning. Despite this first discussion, we spare a discussion of the main mechanisms until all rounds are performed. Table 4.1 presents the result during one of our courses.

	Avg. sum of royalties	Avg. quantity	Avg. joint profits
Round 1: Separation	7.750	4.250	32.250
Round 2: Separation	8.125	3.875	30.125
Round 3: Coordination	6.000	6.000	36.000

Table 4.1: Summary statistics of an exemplary realization (amounts in €).

We typically observe royalties of around 4€ in the separation rounds. There is usually some variation as some students demand less, because they realize early on that a symmetric strategy with royalties of 3€ is the cooperative solution. On the other hand, other students are thinking more about their own profits and set a higher royalty, especially, if the paired patent owner went for the cooperative solution in the first round. In contrast, there is usually very little variation in the third round. Most of the students quickly understand that a (total) royalty of 6€ maximizes the joint profit.

We use the latter observation as a starting point for the discussion and ask why royalties of 3€ for each patent owner do not constitute an equilibrium in the separation case, i.e., we derive the theoretical equilibrium together with the students. One way to derive it, is to show the best-response functions for patent owner 1 if patent owner 2 would choose a royalty of 3€:

Table 4.2 shows that joint profits are maximized if $r_1 = 3$. However, a symmetric strategy $r_i = 3$ does not constitute an equilibrium, because if patent owner 1 expects $r_2 = 3$, then it will be

r_1	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
π_1	0	8	14	18	20	20	18	14	8	0
π_2	0	24	21	18	15	12	9	6	3	0
$\pi_1 + \pi_2$	0	32	35	36	35	32	27	20	11	0

Table 4.2: Best response of patent owner 1 if patent owner 2 sets $r_2 = 3$ (amounts in €).

profit maximizing to respond by choosing $r_1 = 4$ or $r_1 = 5$. This happens not only at the expense of the other patent owner; even worse, the negative effect on π_2 is larger than the positive effect on π_1, such that welfare decreases. By maximizing π_1, patent owner 1 exerts an externality on patent owner 2. Clearly, the same is true for patent owner 2. Patent owner 2 also maximizes its profits and exerts an externality on patent owner 1. Consequently, both set a royalty above the cooperative optimal royalty level (3€). This problem emerges because individual patent owners do not internalize the externalities, i.e., they do not take into account the negative effect of its royalty on the profit of the other patent owner. It is rational to do so, but it leads to too high royalties compared to the joint profit maximizing level.

The remaining question is then to determine the equilibrium. Table 4.3 shows that none of the patent owners has an incentive to deviate from a royalty of 4€.

r_1	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
π_1	0	7	12	15	16	15	12	7	0	0
π_2	0	28	24	20	16	12	8	4	0	0
$\pi_1 + \pi_2$	0	35	36	35	32	27	20	11	0	0

Table 4.3: Best response of patent owner 1 if patent owner 2 sets $r_2 = 4$ (amounts in €).

This observation shows that fragmented ownership of patent rights stacks individual royalties on one another. The sum of the royalties is higher compared to a situation with concentrated ownership of patent rights. Fragmented ownership of complementing international property rights creates the problem of royalty stacking which is, everything else equal, negative for the IPR owners and society.

Once the royalty-stacking problem is clarified, remedies to the problem can be discussed. First, we usually introduce the concept of patent pools. A patent pool is a consortium in which owners of complementing patents pool their patents. The pool then licenses the patent rights to pool members and external parties. It can therefore also include a form of cross-licensing. Patent pools can be discussed from a competition policy and law perspective, for example, against the background of patents that complement and substitute each other. The introduction of patent pools can also be used to talk about technology standards, as standard-essential patents are by definition complements.

Second, different royalty structures can, in theory, remedy the royalty-stacking problem. In particular, setting a fixed fee instead of a variable royalty, would solve the production inefficiency. However, whereas that is true for the stylized environment of the experiment, there are also downsides of fixed fees. Hence, the discussion can be used to motivate or relate to a lecture discussing different fees in royalty contracts, or to a lecture on the market for innovation in more general.

Finally, we like to challenge students to think about the mechanism of double margins beyond licensing. The effects originate from the fact that the patents are complements. Whereas joint pricing of substitutes leads to higher consumer prices, joint pricing of complements leads to lower prices. Hence, joint pricing of complements does not benefit only the producers but also consumers. We highlight that the same mechanism is present in a variety of settings. Our favorite example for a business student audience, is pricing along the vertical supply chain within organizations. Pricing inputs in the supply chain is by definition pricing of complements. This reminds students of management courses of their lectures on transfer pricing and clarifies that the mechanism is not exclusively observed in the licensing case.

4.3 Cross-licensing

4.3.1 Learning goals

1. Knowledge on the concept of cross-licensing.

2. Understanding the strategic interaction in cross-licensing agreements.

3. Understanding of the tension between competition law and intellectual property law.

4. Learning about strategic interaction and game-theoretical considerations.

4.3.2 Procedure

The second experiment on cross-licensing will take around 60–70 minutes including discussions. The instructions can be found in Appendix D.3.

In the experiment, each student takes the role of a manufacturer. Two manufacturers are matched with one another at the start and remain matched throughout the experiment. The manufacturers compete with each other on a product market. However, they require access to technologies of a competitor. The technologies are protected by patents. Therefore, they enter into a cross-licensing agreement with a reciprocal royalty fee f per unit sold. For simplicity, we assume that the manufacturer has no additional costs (or, alternatively, only fixed costs). Hence, both manufacturers do not only pay for a license, they also earn licensing revenues. This can be best seen in the profit function of one of the manufacturers (in this case 1):

$$\pi_1 = p_1 q_1(p_1, p_2) - f q_1(p_1, p_2) + f q_2(p_1, p_2) \tag{4.1}$$

Equation 4.1 shows that in addition to the product market revenues, the manufacturers do not only pay for a license, they also earn licensing revenues from their competitor. As the last term in the equation increases in the sales of the competitor, it adds an additional strategic dimension to the pricing decision of the manufacturers. As we will see, f matters for the pricing decision even though the licensing costs and revenues cancel each other in a symmetric equilibrium.

The manufacturers can choose any even number between 0€ and 24€ as their price.[12] The demand function for the two companies depends on the difference between the prices and is given by Table 4.4.

$p_1 - p_2$ (in €)	≥ 10	8	6	4	2	0	-2	-4	-6	-8	≤ -10
q_1	0	2	4	6	8	10	12	14	16	18	20
q_2	20	18	16	14	12	10	8	6	4	2	0

Table 4.4: Demand function depending on p_1 and p_2.

The experiment starts with the distribution of the instructions and students reading them carefully. Then, we use numbered record sheets to match the students. It is recommended to match students that sit relatively far away from each other in order to hinder communication such that explicit cooperation does not affect the result. We performed the experiment with up to 80 students, i.e., 40 groups. As with Experiment 1, one may consider forming groups representing one decision maker for even larger classes. Afterwards, we prepare a spreadsheet, and either write the key ingredients of the set-up on the blackboard or display them on the projector. After the students finished reading, it is important to explain the procedure once more and to clarify questions.

We ask students to write down their decision on the record sheet. After each round, they submit their decision, and we return the record sheets after we have entered it into our spreadsheet.

The experiment consists of two phases. In the first phase, the reciprocal fee equals $f = 2$. In

[12] This restriction on the price choice is imposed to ease the discussion after the experiment. We explain the students that this is a pure simplification with no major impact on the outcome.

the second phase, it equals $f = 6$. We usually run two to three rounds of phase 1, because it takes students a while to figure out the optimal strategy. Whereas the first round takes the students usually around 10–15 minutes, the other rounds take significantly less time.

We typically only run one round of phase 2. Because the set-up is very similar to phase 1, students understand the basic strategies involved, and tend to answer also rather quickly.[13] Even though playing only one round makes a coordination on prices of 24€ theoretically more likely, students are typically still in competition mode and usually not all go for that choice.

4.3.3 Discussion

Similar to Experiment 1, we do not strictly differentiate between the experiment and the discussion. After each round, we ask students for their considerations, but we spare a discussion of the main mechanisms until all rounds are performed. Table 4.5 presents the result during one of our courses.

	Average price	Average joint profits
Round 1: $f = 2$	18.875	337.000
Round 2: $f = 2$	16.250	290.000
Round 3: $f = 2$	14.250	275.000
Round 4: $f = 6$	17.375	351.000

Table 4.5: Summary statistics of an exemplary realization (amounts in €)

The equilibrium prices in phase 1 equals 14€. Table 4.5 shows that the prices in the first rounds were significantly higher, because students see quickly that cooperating and setting 24€ each is jointly optimal.

How intensely the individual rounds should be discussed, depends on the group size. In small groups, our experience shows that students sustain a higher level of cooperation. The lack of variation may lead to little discussion. In that case, we show that 24€ does not constitute an equilibrium directly after round 1. For larger classes, that is less of a problem, and the discussion can be delegated to the end of phase 1.

In order to show that 24€ does not constitute an equilibrium, we analyze the best response to the competitor's price of 24€. Table 4.6 shows that the best response equals a price of 18€ or 20€.

In the second and third round, the students understand the game better, and the prices

[13]In case the students had difficulties understanding the change, one can consider running an additional round.

p_1	**24**	**22**	**20**	**18**	**16**	**14**
π_1	240	256	264	264	256	240
π_2	240	200	160	120	80	40
$\pi_1 + \pi_2$	480	456	424	384	336	280

Table 4.6: Best response of manufacturer 1 if manufacturer 2 sets $p_2 = 24$ (all amounts in €).

converge towards the equilibrium price 14€. Table 4.7 shows that 14€ is indeed the equilibrium price.

p_1	**18**	**16**	**14**	**12**	**10**
π_1	124	136	140	136	124
π_2	180	160	140	120	100
$\pi_1 + \pi_2$	304	296	280	256	224

Table 4.7: Best response of manufacturer 1 if manufacturer 2 sets $p_2 = 14$ (all amounts in €).

In phase 2, the equilibrium price equals 22€. We usually indeed observe that the prices increase after the increase of the reciprocal fee.

We start the discussion by showing that 22€ does indeed constitute an equilibrium. For that purpose, we use an adjusted version of Table 4.7. After the students understand the equilibria in phase 1 and 2, we discuss why they are different. It is helpful to write down the profit function of one of the manufacturers (equation (4.1)).

The profit equals the revenues minus the outgoing licensing payment plus the incoming licensing payment. We often start with referring to the symmetric equilibrium, and raise the question why f affects the equilibrium prices if the incoming and outgoing licensing payments cancel each other. This puzzles many students. However, there are usually some students that understand that f matters because it affects their willingness to increase the price. The higher f is, the less they are concerned with raising the price. There are two reasons. First, the profit margin is smaller. Second, losing own production is less problematic as it is compensated with higher incoming licensing revenue.

Students typically start thinking quickly "at the margin". At this point, looking at the first-order condition of the manufacturers may help:

$$\frac{\partial \pi_1}{\partial p_i} = \underbrace{p_1 \frac{\partial q_1(p_1, p_2)}{\partial p_1} + q_1(p_1, p_2)}_{<0} \underbrace{- f \frac{\partial q_1(p_1, p_2)}{\partial p_1}}_{>0} + \underbrace{f \frac{\partial q_2(p_1, p_2)}{\partial p_1}}_{>0} = 0 \tag{4.2}$$

Equation (4.2) shows that the last two terms increase in f. Hence, the first part has to become even smaller (more negative), i.e., p_1 is larger. More intuitively, the equation shows that for a larger f, the latter parts – the licensing payments – become more relevant. For a larger f, the company saves outgoing licensing payments when it increases the price, and at the same time, it receives more incoming licensing payments. Hence, a larger f increases the incentives to increase the price. That the payments cancel out in equilibrium, is then a consequence of the symmetry between the manufacturers. If one wants to avoid derivatives, it is also possible to argue with plus and minus signs in equation (4.1).

The experiment illustrates how reciprocal royalty payments dampen competition, and drive up prices. As the royalty f is endogenous in a cross-licensing agreement, the patent owners have incentives to choose f relatively high, driving up prices for consumers.

The results can be used to discuss examples of such cross-licensing agreements in practice. In addition to the details of licensing contracts (OECD 2019), standard-essential patents seem to be particularly interesting (see, e.g., Baron and Spulber 2018). Furthermore, the relationship of licensing and antitrust concerns are of importance for future decision makers. FTC (2017) serves as a good starting point for a detailed discussion of the latter.

It is also useful to link the two experiments together. It is worthwhile to recall what we discussed in the end of the first experiment: patent pools as one potential way to resolve the royalty-stacking problem. However, patent pools often include cross-licensing agreements. Experiment 2 shows that cross-licensing in patent pools may have anti-competitive effects. This implies a potential downside of using patent pools to solve the royalty-stacking problem. Both experiments can also be used as starting points for a deeper discussion of patent thickets (see, e.g., Shapiro 2000).

Finally, in order to highlight the importance of the mechanism beyond technology licensing, one can link to another setting where the mechanism is present. In most communication networks, network operators charge reciprocal access fees (termination fees) for consumers to access other networks. One example is the mobile phone market (see, e.g., Armstrong 1998). Here, consumers choose their mobile network operator independently, and call other consumers regardless of their choice of network operator. When calling a participant in another network, operators charge a termination fee. These termination fees were initially set endogenously by the telecommunication companies and led then to abusively high fees. They have later been regulated ex-ante by telecommunication authorities.

More in-depth analysis of royalty stacking can be found in, e.g., Lemley and Shapiro (2007), Rey and Salant (2012) and Schmidt (2014); more details on cross-licensing in, e.g., Katz and

Shapiro (1985), Fershtman and Kamien (1992) and Jeon and Lefouili (2018). Finally, combinations of the two topics are analyzed in, e.g., Lerner and Tirole (2004) and Shapiro (2000).

4.4 Implementation for digital teaching

The classroom experiments are also well-suited for online teaching. We have performed both experiments successfully using video telephony software. The experiment and discussion can proceed almost according to the instructions. The relevant material should be made available for download during the lecture. The easiest way of forming groups is to use the breakout rooms. Each breakout room – which can consist of just one student – represents one decision maker and is matched with one other breakout room. In small classes, the decisions can be collected by visiting the breakout rooms. For larger classes we recommend using an additional digital survey tool, for example, Google forms. The survey should ask for the group ID and the decision. Discussions after each round take then place in the plenary session.

4.5 Conclusion

Intellectual property rights are on the rise in our more and more technology-driven business world. Therefore, it is increasingly likely for economics and business students to deal with them during their future career. Consequently, IPRs should be more heavily included in the curriculum of economics and management degrees. We offer two classroom experiments that aim to create an engaging learning environment on technology licensing. Both experiments are related to patent pools. Patent pools offer a solution for the royalty-stacking problem, and they usually involve cross-licensing. Whereas the former is positive both for the companies involved and the society, the latter can be welfare decreasing.

We designed the experiments not only to teach the students these specific topics but also to motivate a further discussion on related topics. As both experiments are on licensing, they also offer the chance to discuss the different components of licensing contracts in general. The introduction of patent pools serves as an opportunity to introduce technology standards and standard-essential patents. Finally, the experiments can be used to highlight the general tension of intellectual property and antitrust law. Whereas intellectual property law aims to give innovation incentives with monopoly rights of a technology, antitrust law works against monopolies.

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Appendix D

D.1 Required material

- Instructions (see below)
- Numbered (A1, B1, A2, B2,...) record sheets to match groups (see below)
- Spreadsheet to record the results

D.2 Royalty stacking: Instructions

In this experiment, each of you will be assigned the role of a patent owner. Two patent owners will be matched with one another at the start of the game and will remain matched throughout the game. As a patent owner, you will license your technology to a manufacturer. In order to produce, the manufacturer requires access to both of your technologies - she is not able to produce otherwise.

Both patent owners will independently set their per unit royalty. The production level of the manufacturer depends on the sum of the royalty payments and is given by:

Sum of royalties (in €)	12	11	10	9	8	7	6	5	4	3	2	1	0
Units sold	0	1	2	3	4	5	6	7	8	9	10	11	12

Your job:

- Select the per unit royalty for your technology that maximizes your profit. You make this decision at the same time as the second patent owner.
- As you only grant access to your technology, there are no additional costs. Thus, your profit is simply your royalty multiplied by the units produced by the manufacturer.
- At the end of each period, please record your per unit royalty, the number of units sold, and your profits on the record sheet provided.
- All patent owners are reading the same instructions as you are now.

D.3 Cross-licesning: Instructions

In this experiment, each of you will be assigned the role of a manufacturer. Two manufacturers will be matched with one another at the start of the game and will remain matched throughout the game.

As a manufacturer, you require access to the technology of your competitor protected by a patent. At the same time, you own a patent that protects another technology that is required for production by you and your competitor. You enter into a cross-licensing agreement, and pay each other a reciprocal per unit royalty (i.e., a royalty rate that applies for both of your technologies) of 2€.

Both of independently set your final prices independently. You are able to set one of the following prices:

Possible prices (in €)	0	2	4	6	8	10	12	14	16	18	20	22	24

Your demand depends on the difference of prices:

Your price - other's price	≥10	8	6	4	2	0	-2	-4	-6	-8	≤-10
Your quantity	0	2	4	6	8	10	12	14	16	18	20
Other's quantity	20	18	16	14	12	10	8	6	4	2	0

Your job:

- Select the price that maximizes your profit. You make this decision at the same time as the second patent owner.
- You have no production costs in addition to the royalty . Thus, your profit is given by (Your Price - 2 €) · Your Quantity + 2 € · Other's quantity
- At the end of each period, please record your price, the number of units sold, and your profits on the record sheet provided.
- All manufacturers are reading the same instructions as you are now.